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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD CONFERENCE PROCEEDINGS 540

The Support of Air Operations under Extreme Hot and Cold Weather Conditions

(Les Opérations Aériennes en Environnement Extrême Chaud/Froid)

Papers presented at the Aerospace Medical Panel Symposium held in Victoria, Canada, 17th—21st May 1993.

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North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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Preface

Extreme temperatures, both hot and cold, can severely restrict the ability of aircrew and support personnel to accomplish their missions. Under emergency conditions of bail-out, ejection and ditching of fixed or rotary-wing aircraft on land or in water, the survival rate of aircrew and passengers is also affected by the intensity of thermal stress experienced and the duration of exposure to the thermal stress. This has all recently been borne out by the experience of intense air operations in the Gulf War.

This Symposium reviewed the operational conditions experienced under extreme hot and cold weather.

The papers presented at this Symposium highlighted recent advances in thermal physiology, clothing sciences, personal flying equipment, and microclimate cooling. Emphasis was placed on the potential applications of these advances in situations where thermal stress, or the expectation of thermal stress, may confound the efficient achievement of mission objectives.

Préface

Les températures extrêmes, qu'il s'agisse du chaud ou du froid, peuvent avoir pour effet de réduire considérablement les capacités des équipages et du personnel de soutien dans l'exécution de leurs missions. Dans les conditions de survie qui suivent le saut en parachute, l'éjection, et l'atterrissage forcé en avion ou hélicoptère, tant au sol que dans les eaux maritimes, le taux de survie des équipages et des passagers dépend, dans une certaine mesure, de l'intensité du stress thermique éprouvé, ainsi que de la durée de l'exposition à ce stress thermique. L'ensemble de ces éléments a été confirmé récemment par l'expérience des opérations aériennes intensives de la guerre du Golfe.

Ce symposium a examiné les méthodes opérationnelles testées dans des conditions météorologiques d'extrême froid et d'extrême chaud.

Les communications présentées lors du symposium ont mis au premier plan les progrès réalisés récemment dans le domaine de la physiologie thermique, des sciences des vêtements, de l'équipement de vol personnalisé et de la micro-climatisation. L'accent a été mis sur l'application potentielle de ces réalisations aux situations où le stress thermique, ou la possibilité du stress thermique, risque de compromettre l'accomplissement des objectifs de la mission.

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WELCOME ADDRESS

by

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I would like to begin by thanking your Chairman, Dr. Vogt, for his invitation to participate in this opening ceremony. Unfortunately, due to conflicting commitments, the Surgeon General, MGen Morissett, was unable to be with you today but, on his behalf, I am delighted to welcome you all to this Victoria Meeting of the Aerospace Medical Panel. I have been fortunate to participate in a limited number of these panels in the past and I have no doubt that the AGARD Aerospace Medical Panel provides us all with an outstanding forum for discussion of new advances and concepts. At this time I would like to particularly welcome those of you attending from outside of Canada. We are fortunate to be in a location which I personally consider to be one of the most beautiful parts of the country.

The problems of thermal stress and strain for the air person have been around since the beginning of flight. Around 3500 BC, Greek Mythology tells us that Daedalus built wings of feathers for himself and Icarus, his son. These wings were secured with thread and fastened on by wax. Daedalus ordered Icarus to fly close to him, neither too high, nor too low. But, Icarus was a poor wingman and didn't listen to his leader. Fascinated with the thrill of flight, he soared close to the sun. The heat melted the wax, his wings collapsed and he fell into the sea and was drowned. This is likely to be the first account of an airman who drowned from ditching resulting from exposure to extremely hot conditions. We have to travel much further ahead in history to find the first account of an airman exposed to extremely cold conditions. This was J.A.C. Charles who made the first ascent in a hydrogen balloon from the Tuileries Gardens in Paris on December 1st, 1783. His second trip that same day was a rapid ascent to 2,750 metres when he complained of severe cold and difficulty in clearing his ears.

During the First World War, there was considerable personal improvisation; airmen on both sides copied the clothing worn by motorists and motorcyclists. By 1916, it was a normal operation to fly at 20,000 ft in an open cockpit. Knee-length leather coats and thigh-length "fug boots" were particularly popular with officers in the Royal Flying Corps and the Royal Naval Air Service. Vaseline or Lanolin was often smeared on the face in a vain attempt to prevent frostbite; in the severe cold it simply froze to a solid state and made matters worse. Sidney Cotton accidentally found out that his dirty overalls, covered with aircraft oil and grease were warmer than a clean flying suit. So, his famous weather-proofed Sidcot suit came into being. It was to see Service into the 1940's. Both sides used electrically-heated suits in their attempts to combat the cold. However, they were not the complete solution. A windmill generator provided power for the heating elements, but control on the current was poor, so that when an aircraft dived, overgeneration of electricity produced severe finger burns. Good clothing insulation was required and the problem, then as now, is a compromise between the need to protect against cold while still retaining mobility. By 1919, U.S. Navy crews flying the Curtiss flying boats transatlantic wore heavy "Dreadnaught safety suits" made of rubberized fabric and filled with kapok. They suffered from just the problem I mentioned. These suits were heavy, bulky and not that comfortable to wear.

Admiral Byrd made the first flight over the North Pole in 1926, protected by an eskimo parka made of reindeer skin which was warm in temperatures down -60°C. Any effort to improve thermal protection for aviators had been centered around protection from the cold. Those aircrew that served in the Middle East and India between the Wars came to realise this. One Wing Commander recalls: "What I remember is the pitiless sun, burning, burning down with an intolerable stare". He flew in an open-neck shirt and a handkerchief around his neck to protect it from the sun.

Although open cockpits had virtually disappeared by the outbreak of the Second World War, performance, however, had improved to such an extent that 40 - 50,000 ft was quite achievable. In the first half of the war, engine heaters did not develop as quickly.

Self-improvisation was still evident on the Allies side; one RAF officer was reported to fly with Indian moose hide moccasins and up to five pairs of loose stockings just to keep his feet warm. Some of the stories, especially for bomber crew, sound incredible to us today. I quote: "Such was the condition of the navigator and wireless operator at this stage, that every few minutes they were compelled to lie down and rest on the floor of the fuselage. The cockpit heating system was useless. Everyone was frozen and

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

had no means of alleviating their distress. The navigator and Commanding Officer were butting their heads on the floor and navigation table in an endeavor to experience some other form of pain as a relief from the awful feeling of frostbite and lack of oxygen.".

The Irvin and Taylor Suit in the U.K. and the Shearling suit in the U.S.A. were to help the aircrew especially when reliable electrically-heated vests and gloves could be attached. By December 1941, the RAF had issued 1000 electrically-heated suits to tail turret gunners.

German aviation medicine was far more advanced than that of the Allies. At the outbreak of the war, the Luftwaffe already had a series of excellent flying clothing outfits inservice that suited all their needs including electrically heated gloves and socks.

Good cabin heating remained the best solution and this came in the last two years of the War.

So far, I have only alluded to the problems of heat as that experienced by aircrew in the Middle East and India between the Wars. During the Second War, both German and Allied pilots flew under extremely hot and dusty conditions in the Western Desert; with minimum water rations in their survival pack, the survival rate was even worse if one was shot down over the Mediterranean. The Royal Naval Air Service found one big advantage of the Frank anti-G suit. It contained one gallon of fresh water in its bladder that could supplement the meagre survival rations.

In 1946, the Talbot Committee discovered that in World War II, that the Royal Navy lost one-third of their officers and men in action and two-thirds in the survival phase, over 30 - 40,000 officers and men of the Royal Navy, many of them naval aviators, died of a combination of drowning and hypothermia.

As a result in the 1960's the Royal Navy introduced the quick don "once only suit" which certainly paid its way during ship abandonment in the icy South Atlantic Ocean in the Falkland's War. Of the Royal Navy deaths, 65 were killed in action and only 12 occurred between ship abandonment and rescue, a complete reversal of the World War II figures. On the Argentinean side, of the 770 who abandoned the General Belgrano, 25 died principally due to exposure. In much worse sea conditions and extended rescue times, the issue of a "once only suit" would have improved their survival rate. In February of this year, the saving of 11 fishermen's lives from the Scallop dragger Cape Aspy, in 4°C water off Nova Scotia was attributed to them wearing the ship abandonment suits that are now being manufactured to our new Canadian Standards.

With the advent of full pressure suits and impervious NBC equipment, conditions have worsened for aircrew operating in the heat. Liquid or air-conditioned clothing is the part-answer to this problem - the most successful so far being the liquid-conditioned system introduced by NASA into the Apollo space suit. On the military side, in the 1960's, 70's and 80's, funding for the development of such systems has always been slim. Any novel ideas that have been generated have never really been accepted by the designers and manufacturers of aircraft. The principal stumbling block has been that the equipment takes up a valuable place in the cockpit, is too bulky or heavy, consumes too much electrical power, is simply too expensive, or, far more shortsightedly, the operators have not been convinced that there was any need for it in the first place. They were to change their tunes in a hurry when the Gulf War crisis erupted. In outside air temperatures of 45°C, runway repair crew could only work for 20-30 minutes at a time, but you will hear more of this in your symposium. I am sure I don't need to remind you that trigger spots such as the countries which lie around the Northern borders of Africa adjacent to the Sahara Desert may require our presence in the next 25 years. Mauritania, Western Sahara, Morocco, Algeria, Tunisia, and Libya receive up to 4000 hours of annual direct steep angle sunlight (by comparison Paris gets 1700 hours). Azizia in Libya holds the record temperatures of 58°C, while in the winter air temperatures can drop to freezing at night and rise to 32°C by noon. So we have a long way to go to ameliorate the heat strain imposed on our aircrew and maintainers in the extreme heat.

Ladies and gentlemen, I have very briefly high - lighted a few of the problems of the air operation under extreme temperatures. The problems have not changed since the time of Icarus and we do not by any means have all the solutions. It is many years since the aeromedical community of NATO had a symposium on applied thermal physiology and certainly this one promises to be both stimulating and interesting. The topics range from pure thermal physiology to applied protective clothing design and from new technology in personal cooling systems to the treatment of hypothermia. I am particularly pleased to see presentations from eight different NATO nations.

With these few words, I am delighted to open this 75th Panel Meeting and to wish you all success in your deliberations.

TECHNICAL EVALUATION REPORT

by

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1. INTRODUCTION

The Aerospace Medical Panel Symposium on "The Support of Air Operations under Extreme Hot and Cold Weather Conditions" was held at Canadian Forces Base Esquimalt, British Columbia, Canada from May 17 to May 20, 1993.

2. THEME

Extreme temperatures, both hot and cold, can severely restrict the ability of aircrew and support personnel to accomplish their missions. Under emergency conditions of bail-out, ejection and ditching of fixed or rotary-wing aircraft on land or in water, the survival rate of aircrew and passengers is also affected by the intensity of thermal stress experienced and the duration of exposure to the thermal stress. This has all recently been borne out by the experience of intense air operations in the Gulf War. This symposium reviewed the operational conditions experienced under extreme hot and cold weather. The papers presented at this symposium highlighted recent advances in thermal physiology, clothing sciences, personal flying equipment, and microclimate cooling. Emphasis was placed on the potential applications of these advances in situations where thermal stress, or the expectation of thermal stress, may confound efficient achievement of mission objectives.

3. PURPOSE AND SCOPE

The purpose of this symposium was to address the potential to enhance human performance in hot and cold temperature extremes by reducing the extent of physiological and performance impairments, and by furthering an understanding of those factors influencing survival during heat or cold stress. Keynote speakers included a Canadian airforce medical officer who survived a winter aircraft crash and subsequent blizzard conditions while awaiting rescue in the Canadian Arctic, someone with first hand experience of coping with the threat of hypothermia. Experience in coping with the other temperature extreme was garnered from an American army flight surgeon who experienced action in support of medical operations during the Gulf War and who was ultimately shot down and taken as a prisoner of war. The range of expertise participating in the symposium was reflected by presentations in the following fields: operational medicine, pathology, nutrition, energy metabolism, biophysics, life support equipment development, applied physiology, clothing sciences, biophysics, mathematical modeling, performance assessment, and simulation and training. Participants included scientists, engineers, medical practitioners, and trainers from military services, government and private laboratories, universities, and industry. There were over 140 registered attendees, representatives from all NATO countries except Iceland, and guests from Australia and Sweden.

4. SYMPOSIUM PROGRAM

The emphasis of the symposium was on physiological and medical implications of air operations in hot and cold environments, and means of alleviating temperature stress and strain, the objective being to minimize performance impairments that might otherwise accrue.

The symposium consisted of six sessions: three sessions on cold stress, two sessions on heat stress, and one session on clothing and equipment developments for aircrew protection from temperature stress.

5. TECHNICAL EVALUATION

The need for this symposium was clearly stated in opening remarks by both the Deputy Surgeon General of the Canadian Forces, Brigadier General W.A. CLAY, and by the Programme Chairman, Captain (N) C.J. BROOKS (CA). They reminded the participants that at least a decade had passed since the last

major scientific gatherings in which the human performance implications of thermal stress in a military setting were discussed. Such symposia provide the knowledge that is used to train military physicians, medical support personnel, and aircrew about the principals of protection and survival in thermally stressful environments. These opening comments reminded the participants that projections about the geographical locations of likely "trigger spots" in the world have tightly associated thermal implications. Such projections, coupled with the recent conflagrations in the Persian Gulf, left no doubt about the relevance and immediacy of the need to be aware of recent research and development activities in the areas discussed at this symposium.

COLD

The first keynote address (DEGROOT, CA) was a first-hand account of the personal experience of a Canadian Forces medical officer who was a passenger on a C130 aircraft that crashed in October 1991 north of the magnetic North Pole. Weather complicated rescue attempts until 32 h after the crash. During this time the survivors had to deal with temperatures ranging from -20 to -60°C considering the wind-chill factor. This presentation was noteworthy because it served to demonstrate the degree of inaccuracy, and relatively conservative nature of established "survival times" at various temperature extremes; contrasting with a high hypothermia-induced fatality rate that would be predicted given the environmental conditions, only one casualty was directly attributed to hypothermia.

A paper on the prediction of survival times in a cold climate (MAIDMENT, UK) aptly demonstrated the great inter-individual variation that must be considered when attempting to forecast the ability to survive from such a disaster. This paper also emphasized that the empirical data from controlled human experiments about responses to cold stress are collected before severe hypothermia ensues. Thus, survival time models should be considered as being biased because the kinetics of physiological variables are assumed to follow a similar pattern with the intensity and duration of cold stress which scientists cannot ethically induce in a laboratory experiment.

The use of mathematical modeling for predicting the effects of thermal stress is not limited to predicting survival times. DAANEN (NE) reported research findings confirming that when finger temperature drops below 15°C then dexterity begins to suffer markedly. Such information has been used to develop a computer program used by the Royal Dutch Meteorological Society to predict exposure times until loss of dexterity to a pre-specified limit.

The relevance of hypothermia-related research and development activities by the military was further supported by KRAEMER's (GE) review of microscopic and macroscopic post-mortem findings for deaths after aircraft ejection over water; he concluded that death is more frequently caused by hypothermia than drowning or by blunt trauma in personnel who ditch in water. Along a similar vein, the incident report by MAYR (GE) was the case of aircrew who ejected from two aircraft that crashed over water; the crews ditched into 11°C water and rescue occurred 1.5-2.25 h after the crash. Four of the five crew members survived, while the lone fatality was attributed to hypothermia.

BOHEMIER (CA) discussed a confounding factor when dealing with immersion hypothermia. There is a high frequency of hypothermia immersion victims found with evidence that seasickness may have been a significant contributory factor to death. His report that 35-40% of survival training students become totally incapacitated due to the combination of seasickness and cold water immersion stimulated several other anecdotal reports about the significance of the problem of seasickness. There was some discussion whether it would be preferable to simply teach people to adapt and become accustomed to the feelings of seasickness, or whether a pharmacological aid would be preferable. The consensus was that the latter was the preferred strategy for the military because adaptation requires repeated and frequent exposures to the stimulus. BOHEMIER pleaded for more research into new effective and rapidly acting medication.

Reports of field operations in cold environments were the focus of other presentations. The paper by GAUTVIK (NO) was an intriguing first-hand account of his participation in a 1,400 km unsupported trek to the North Pole; it demonstrates that such a trek at an average temperature of -30°C for 100 days

can be "enjoyed" given the availability of appropriate life support equipment, food and clothing.

COLESHAW (UK) discussed research showing that even mild hypothermia causes very significant impairments of cognitive functions such as errors in judgment, mathematical reasoning, etc. Thus, the importance of avoiding such thermal stress becomes all the more important for even routine military activities, such as those reviewed by STEELE-PERKINS (UK) and COLESHAW (UK), exemplified by the medical and transportation support of the British Antarctic Survey.

Contrasting with the usual dogma of dealing with cold stress by protecting the soldier from the stress, in the second session several papers discussed the potential to influence the rate of heat production by humans. JACOBS (CA) described research that documented the quality and quantity of macronutrients used by shivering muscles to produce heat. His presentation and that by MEKJAVIC (CA) suggested that depleted carbohydrate stores, both within the shivering muscles and in the bloodstream, can have a profound effect on cold-induced increases in heat production by the body and, thus, the rate of onset of hypothermia. VALLERAND (CA) reviewed attempts to pharmacologically enhance metabolic heat production and thus acutely increase resistance to cold stress; in this presentation it was emphasized that most animal models are poor physiological substitutes for human subjects, thus extreme care must be taken when considering the potential applications of animal research to humans. VALLERAND showed that pharmacological treatments can increase the metabolic response, and thus heat production, during cold stress. As described above, however, there are not sufficient empirical data to decide whether such treatments would have a practical application in the form of a prophylaxis against hypothermia.

Several subsequent presentations addressed hypothermia and its treatment. GIESBRECHT (CA) presented recent research findings that should be passed on immediately to all survival training personnel. His research questions the efficacy of body-to-body rewarming, and suggests that body-to-body rewarming is not warranted for mildly hypothermic, vigorously shivering individuals, and may even be counter-productive. The studies presented by CAHILL (UK), ROMET (CA), and POZOS (US) describe and compare the efficacy and safety of various methods of rewarming of hypothermia victims. It appears difficult to pinpoint one single method of rewarming as being optimum for rewarming in the field. These papers emphasize the necessity for education and training to increase awareness about the advantages and disadvantages of various rewarming methods. After significant discussion, in particular between CAHILL (UK) and VANGGAARD (DE), there was a noteworthy consensus expressed at this meeting, i.e., that the practice of leaving arms and legs out of warm water while rewarming serves no useful purpose and should be abandoned.

HEAT

The papers addressing heat stress were preceded by a keynote address (CORNUM, R., US), relating first-hand experience with this thermal stress during the Gulf War. This flight surgeon related how the Army attack helicopter battalion to which she was attached, experienced temperatures as high as 58°C in an operational setting. Although there apparently were no heat casualties, there were incidents of dehydration and suspected dehydration that were treated immediately with aggressive use of intravenous infusions. In this presentation it was also emphasized that there was little information available to the practitioner in the field about the stability of drugs at such temperatures. It was recommended that labeling should include such information.

A review by NUNNELEY succinctly stated the combination of factors that cause heat stress for aircrew: workload, clothing, and environment. Despite this knowledge being available, the lack of communication between scientists and the military end-user was pointed out by MACMILLAN (UK); his review of the British experience during the Gulf War, the implications of heat stress for aircrew coping with the threat of operations in an NBC environment, and the lack of adequate preparation, was summarized as follows: "...trained for Europe, dressed for the jungle, and sent to the desert."

The Desert Shield experiences of another medical officer (CORNUM, C., US) attached to an airforce group of 35 pilots and 600 support

personnel emphasized the importance of water availability at a multitude of sites. Also ground personnel worked in two twelve-hour shifts so that there was equal exposure time to the most intense periods of sunlight for each shift. The effect of aging on the efficiency of body temperature regulation was discussed because older reserve personnel presented different problems than did regular duty personnel.

Applied nutrition was the focus of a few papers by JONES (US), MEYER (US), and GARCIA ALCON (SP). Although it seems intuitively logical that enforced drinking will improve hydration status, a study was reported by GARCIA ALCON (SP) to confirm this aspect using a practical and culture-specific approach to the phenomenon of voluntary dehydration. Pilots and mechanics in the Spanish Air Force were divided into two groups. One group drank *ad libitum* while the other group was forced to consume an additional 500 mL of Gespacho soup in addition to their normal voluntary food/fluid intake. After two weeks of treatment while working in a hot environment, the Gespacho-treated group had significantly better fluid balance. The reader is referred to the paper for the detailed Gespacho recipe; I tried the recipe and found it to be the best-tasting Gespacho I have tried in my vast culinary experience.

KOBRICK (US) presented an empirically based questionnaire, covering a wide range of environmental factors (e.g., symptoms, sleep, dehydration, nutrition, sickness, physical exertion, thermal stress, etc.), which can be used to evaluate the degree of thermal distress in the field, and the extent of stress alleviation afforded by experimental manipulations or hardware solutions.

NEW FABRICS, CLOTHING AND EQUIPMENT

The objective of textile/clothing research for the military is frequently to provide protection and comfort simultaneously. SLATER (CA) elucidated the problem inherent with such an objective because these two factors are frequently incompatible when it comes to the desired textile characteristics required to achieve the objective. This was exemplified in the report by SOWOOD (UK); the development of a new extended coverage anti-G suit, for example, greatly increased G-tolerance, but increased the degree of thermal discomfort. Several other papers demonstrated, however, that there have been significant recent advances by the commercial sector that reduce the discomfort level and still maintain protection: e.g., fabrication of buoyant fire protective clothing ensemble (UGLENE, CA), CBW protection (ALLEN, US), variable thermal insulation and buoyancy suits facilitating egress from a downed aircraft (BRAMHAM, UK).

Microclimate cooling was a popular topic (BROWNE, CA; PONGRATZ, GE; FRIM, CA; THORNTON, US; LEJEUNE, FR). There is no doubt about the effectiveness of such cooling, as exemplified by Canada's experience during the Gulf War. FRIM (CA) reported how such cooling of helicopter pilots obviated the thermal stress limitation to maximal exploitation of the aircraft operational capacity during the war. There was a consensus that such cooling was definitely beneficial but that it must be an integral component of routine life support equipment worn by the pilot on a regular basis, and not an "add-on."

TIPTON (UK) presented an example of creative, yet simple, equipment development with direct military applications. An emergency kit can be used to re-breathe expired air, more than doubling breath holding time; such kit would greatly facilitate escape procedures from ditched helicopters, for example, by reducing the element of panic associated with the requirement for a rapid egress.

6. CONCLUSIONS

6.1 Technological, physiological and medical advances during the last decade have yielded significant new knowledge that, if appropriately communicated to the "end-user", can enable military operations to be conducted by humans in most thermally stressful geographical locations on our planet.

6.2 Survival training is effective in reducing the casualty rate due to thermal stress, if such training is based on valid scientific findings. The efficacy of such training is dependent on new knowledge being regularly reviewed and incorporated into training curricula.

6.3 Mathematical models of human survival times during thermal stress are useful, but must be viewed with caution since the empirical data

on which such models are based do not include experimental conditions that mimic the degree of stress that can lead to casualties.

6.4 Seasickness may be a contributory factor to death after ditching in cold water.

6.5 Body-to-body rewarming is not warranted for mildly hypothermic, and vigorously shivering individuals.

6.6 During rewarming of hypothermia victims, the practice of leaving arms and legs out of warm water baths serves no useful purpose and should be disbanded.

6.7 Micro-climate personal cooling is an effective method of reducing the degree of heat stress that may otherwise be experienced by aircrew. Such cooling equipment should be an integral component of standard life support equipment worn by pilots on a regular basis.

7. RECOMMENDATIONS

7.1 The human factor is frequently the limiting factor to the effective and efficient employment by the military of technological advances in thermally stressful environments. The content of the symposium made it readily apparent that research and development efforts of both more fundamental and applied natures can result in extending the limits of thermal strain tolerated by humans during military operations. Such efforts need to be continued to keep pace with rapid military hardware/systems developments to ensure an effective integration of the human with the system that he/she is to operate.

7.2 The broad range of subject matter covered at this symposium limited the extent of participation in discussions by participants because of the degree of specialization required to be a knowledgeable discussant. It is recommended that future symposia on the topic of thermal stress of humans should involve meetings devoted to a single subject area, such as: clinical/medical implications, or nutrition, or behavioral aspects.

KEYNOTE ADDRESS 1

SURVIVAL FROM A C130 ACCIDENT IN THE CANADIAN HIGH ARCTIC

by

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Canada

On October 30, 1991 I was a passenger on a C130 Hercules transport aircraft enroute via Thule, Greenland to Canadian Forces Station (CFS) Alert in the Northwest Territories of Canada. CFS Alert, is on the north west side of Ellesmere Island above the 80th parallel, north of the Magnetic North Pole and south of the Permanent Polar Ice Pack. I am a general duty medical officer at Canadian Forces Base Trenton, the medical support base for Alert. Alert is staffed by two military physician assistants (P.A.) who are trained to work independently in isolated locations. CFB Trenton provides a medical officer to relieve the P.A.'s for one week during their six month tour. This was my first operational tasking as a Medical Officer in the Canadian Military.

On the second leg of the journey, we departed Thule on a second plane, with a new crew and a full cargo of arctic diesel fuel. Combining passengers with a cargo of fuel normally is considered unsafe. However, diesel is not explosive and doesn't burn easily at low temperatures. After one and a half hours of flight we were informed that we would land shortly. Not long after, all the passengers having fastened their seatbelts, the plane began sliding along the ground. We did not know at that time that we were twenty kilometres short of the runway at Alert. A deep ravine and a not-yet-frozen river separated us from safety. The plane crashed on a plateau with debris scattered over 2 km along the crash line. The E.L.T.(Emergency Location Transmitter) was activated 1-1/2 km away from the survivors. The plane was completely broken up except for the rearward section of the tail. Fires started on the engines after impact and the cockpit burned in minutes after the aircrew escaped with minor injuries. Of the thirteen passengers and five aircrew aboard the flight, one passenger was killed on impact. Two passengers and the loadmaster died within the hour. The only other fatality, the aircraft commander, occurred 24 hours later as a result of hypothermia. The surviving passengers were thrown more or less clear of the plane as it broke up. I remained strapped to the bench with five others, but clear of any other debris. Fourteen people were now faced with survival until rescue (32 hours later) in -22c temperature and blizzard conditions.

The gist of my discussion will focus on the "Survival Pattern", taught at the Canadian Forces Survival Training School. In order of priority first aid, fire, shelter, signals, food and water form the basis of a survival pattern. Thereafter, I will discuss some psychological aspects.

Administering first aid with no equipment is difficult. None of the first aid kits on the aircraft were found. The principle of the 'golden hour' became evident in the timing of the fatalities, 3 died not immediately but within the first hour. The use of CPR in this

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traumatic, isolated situation had to be discouraged to prevent fatigue which would compromise the survivors. Of the survivors, lacerations, including scalp, were frequent but caused minor blood loss because of rapid coagulation. I am not sure whether the cold temperature freezes blood or clots it but I saw very few bleeding wounds. One survivor suffered burns to his face severe enough to obstruct vision with the swelling, but fortunately had no airway obstruction. Aside from the initial smothering of the flames, no treatment was given. This survivor had haemoglobinuria at rescue, but no permanent kidney damage. Orthopaedic injuries were common and made movement difficult. The arctic clothing, bunny pants and mukluks, provided some splinting. The crash was well above the tree line so no light-weight material was available for splinting. A pelvic fracture was kept as immobilized as possible with transfers done by stretcher (one was found in the debris).

No medications of any kind were available but would have been unnecessary except, perhaps, to ease the pain of the pelvic fracture. From the outset, one member displayed bizarre behaviour including refusing to wear hand covering and being disoriented to time and place. He was completely oriented to person and could give accurate details of his past but throughout the wait for rescue was delusional with such statements as "you still think we are going to be rescued after waiting 5 years" and "there are people in a building just outside waiting for us to come out so they can help us, but you insist on staying in the tail". Because of dried blood on his face, I suspected a moderate head injury but had no way of excluding the possibility of a traumatic stress reaction. This person has no memory of the crash but is now otherwise neurologically normal despite severe frostbite to the hands which necessitated the amputation of most fingers.

Two survivors had no feeling in the lower body which suggested a spinal injury. Keeping them immobile was a priority. They were protected from the elements with sleeping bags and a shelter made from debris. Presently, one is now confined to a wheelchair and the other is recovering from frostbite injuries but is not paralysed.

Thus, although first aid was minimal, most of those who survived the crash would have been classified as "green" initially. The sequence of black, red, yellow or green denotes dead, severely injured, moderately injured and walking wounded respectively. Status would have been downgraded to yellow or red, depending on the degree of hypothermia effects.

The second priority in the survival pattern is fire. After the crash, fires burned in the wing-mounted engines. Because of its visibility in the arctic darkness, when the smoke cleared, the wing became the collection point and maintaining the fire with diesel-soaked cloths and papers became a focus of attention. Flashlights were needed to search for equipment and to collect fuel from the split diesel tanks for the fire. Because of their mobility and by their own motivation, this task was done by the aircrew. Later, when we moved to the tail, fire was no longer possible because of fear of toxic fumes from the insulation if it caught fire.

Shelter is the next priority. In the initial seven

hours after the crash, the weather was clear and the winds calm. The aircrew knew we were within twenty kilometres of Alert and that rescue was imminent. While the aircrew brought packs of equipment to be searched, for useful materiel and brought fuel for the fire, we were content to sit and wait thinking that rescue was not far off. Movement was difficult for many because of their injuries. We sat until the storm began. Then it was necessary to move to a location out of the high winds and drifting snow. In search of shelter, several tents were found, with rips and no poles. The rubber rafts that had inflated during the crash, were damaged, and frozen in unusable shapes. Seven sleeping bags were recovered. Four were used as insulation for the two with spinal injuries and the last three for individuals. The aircrew whose parkas had been lost in the flames of the cockpit were in need of protection from the wind. Their exertions, which had kept them warm, had caused them to perspire. Their sweat was now beginning to freeze on their skin. The snow known as 'popcorn snow' resembled fine sand under an icy crust. It was impossible to construct any kind of wind protection from this snow. Even though the survival manuals advocate not staying in the wreckage, we had few options. The intact tail of the plane was the only structure large enough to provide protection from the mounting blizzard. Lighting a fire inside the fuselage would result in toxic fumes from burning insulation. Therefore, we relied on each others body heat to keep us warm. The insulation lining the walls was pulled down to lie on and to fill the many holes in the natural construction of the floor. Unfortunately, whenever we moved, the lining shifted and we found ourselves lying on the bare metal floor. The major disadvantage of using the fuselage as shelter was the intense cold of the metal. Outside the wind and snow had taken the -22c temperature and created a windchill factor of -60c. The open end of the tail was partially covered with a tent. Another was used as a covering to keep the snow off our clothing. Under the tarp, we arranged ourselves in order to prevent heat loss but left the person with the pelvic fracture and the one with the head injury separate, although close to us, because of their level of pain and agitation respectively.

Considering the geographic and weather situation in which we found ourselves, the shelter chosen was adequate. All those sheltered in the tail survived, except one. The aircraft commander and, for a time, the co-pilot, went out periodically to check on the two injured left bundled outside in their own shelter. This meant walking from the tail less than 30 metres through the blizzard which resulted in cold, fatigue and eventually death from hypothermia for the aircraft commander. We were unaware of the level of his distress until he died. The survivors experienced various signs of hypothermia with increased urine output, decreased sensation in hands and feet and an impaired level of awareness. Frostbite was a problem in recovery but only the person with the head injury and the person with lower body paralysis required amputations.

Priority four - Signals. Our flight was followed 20 minutes later by Boxtop 23, another Hercules transport.

They spotted the fires burning in the wreckage and confirmed our position. At that time movement on the ground at our crash site could not be visualized from the Air. We had yet to find the flares which could confirm our location. Signal distress day/night flares and signal-illumination flares were found in the emergency kits in the debris. During the second to seventh hours the aircrew fired the flares whenever we heard the sound of aircraft. We suspected these to be commercial airliners flying at high altitude. After the first, we did not see another plane. We did not realize that the ground rescue team had seen our flares from across the river valley nor did we see their responding flare. During the storm it was impossible to fire signals although we saw the flares dropped by the rescue planes.

Having found several radios in the wreckage we were able to talk to the rescue planes for a short period of time. The radio batteries quickly became inefficient due to the cold. The last working radio was kept with a passenger in a sleeping bag in an attempt to prolong its battery life. The last communication was a clear reception from the aircraft and a code-like pushing of the transmission button on the ground in response to yes-and-no questions. In the last twelve hours we had to be content with hearing the planes, seeing the dropped flares and knowing that they knew our location. The Emergency Location Transmitter (E.L.T.) continued transmitting our location to the search and rescue satellite until after the investigation team came on site. Finally, the priority of food and water. Survival kits on military aircraft contain survival candy, a carbohydrate-based soft candy designed to provide energy without consuming water in the metabolism as protein or fat would. Each package is sufficient to nourish one person for two days. We had three packages, enough for our group for 12 hours. Because we were not very active, the amount was not critical. The problem with this food source was its cellophane wrapping. The normally soft candies were frozen solid and could not be unwrapped with gloved hands. As the doctor, the candies had been given to me to distribute. In order to unwrap the candies I had to take my arms out of the sleeves of my parka so I could unwrap them with bare hands under my parka and then distribute them one by one.

Water was a concern. Even in a cold environment, water is a necessity. The entire crash site was soaked in diesel. One person who tasted the snow remarked on its contaminated flavour. I recall deliberately considering the advantages/disadvantages of eating snow. The advantage: providing necessary fluid while our bodies were under high stress. The disadvantages: the possibility of contaminants (including hydrocarbons) in the snow, the relatively small amount of water obtainable from a set volume of snow, and most importantly the introduction of near freezing water to the body core when the ambient temperature already held high risk of hypothermia. I chose not to suggest eating snow to the others. At the rescue, we were very thirsty. The offered coffee was not rejected, but simple warm water was preferred. The importance of water for the burned member was emphasized when his urine was seen to be

dark red. Because he was unwilling to urinate while lying in his sleeping bag and was unable to manoeuvre outside of it with no vision, extra fluids before rescue would have complicated the situation. As it was, he suffered no permanent kidney damage. Thus food and water, although limited, were sufficient for our survival period.

There is recent increased attention to critical incident stress and its treatment to prevent post traumatic stress disorders. During the wait for rescue, the survivors in the tail-section discussed family, prior military experience and prior visits to Alert. These discussions were structured around the roll call: the first name of each survivor called every hour by me. Each person was required to answer verbally when called. This served several purposes. It prevented people from falling asleep for long periods, which could be fatal in the cold. The names gave people back their individuality so they were more than a "survivor". Using the roll call everyone was given an opportunity to participate if they chose. At one point a discussion began on the safety of the Hercules aircraft versus other planes. The consensus of passengers with experience was to still choose a Hercules before any other aircraft because of their safety.

On our return to National Defence Medical Centre (NDMC) we underwent, as a group, minus the aircrew, a formal Post-Traumatic Stress Debriefing. Although most survivors had little interest in attending initially, it was a positive experience, beneficial in the long-term recovery psychologically from the incident. Further work in the field of Critical Incident Stress is very important.

In conclusion, the survival pattern taught must be modified for extreme situations. Because of injuries and the storm conditions, movement and active participation in activities focused on survival was limited. The ability of rescue teams to reach us was hampered by the same storm conditions and their arrival was timely and appreciated. Although none of the survivors had previously learned arctic survival, the aircrew did have Basic Survival training. They took charge of the situation and found enough equipment to make our wait for rescue possible.

The cold served as both friend and foe. It decreased swelling, blood loss and pain for some. For others it caused painful frostbite and amputations in the recovery period of the survivor. The weather was the largest contributing factor delaying rescue. With the best laid plans, weather will always be the uncontrollable element limiting success.

Reference

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MEDICAL SUPPORT FOR BRITISH OPERATIONS IN THE ANTARCTIC

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SUMMARY

This paper presents an overview of the work undertaken and support given to members of the British Antarctic Survey, discussing some of the environmental hazards to which the personnel are exposed.

BRITISH ANTARCTIC SURVEY

The British Antarctic Survey is responsible for all of the British Governments scientific research in the Antarctic, South Georgia and the South Sandwich Islands. The aim of the British Antarctic Survey is to carry out a balanced and optimum programme of first-rate scientific research in the Antarctic, of global as well as regional relevance. Currently there are four permanent research stations; two geophysical observatories, at Halley and Rothera; one biological laboratory at Signy; and a centre of support for earth sciences, including airborne remote sensing research at Rothera. Seabird and seal research is undertaken at Bird Island, a small field station. The scientific programme is based on a multi-disciplinary research strategy, which will be taken forward into the next century. Visiting scientists from University departments also make use of the bases.

The Survey began in 1943, in wartime, as a naval operation. In 1945 it became the Falkland Islands Dependencies Survey, before, in 1962, the British Antarctic Survey, BAS, was formed. The five research stations have been established in the region of the Antarctic Peninsula, and are now manned all year round. In the past it used to take the best part of a year to get the personnel into position to undertake exploratory work followed by a second season for a limited amount of research to take place, returning home during the third season. Advances in air operations mean that some scientists are now able to reach the Antarctic, and even their field sites, by air, and thereby conduct their work through the summer season, before returning home by air. This allows the scientists to follow up and discuss their work with colleagues at home in the UK before planning the next phase of their work.

The research stations are positioned at Bird Island, Signy, Faraday, Rothera and Halley.

(1) **Bird Island** on South Georgia is the least remote base, with a winter population of only 3 staff, though there may be up to 10 staff in the summer.

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(2) **Signy** is the biological station, located on one of the South Orkney Islands. A large part of Signy Island is covered by permanent ice, with snow falling on about 280 days of the year. Activities include a diving facility. In winter, staff dive beneath the ice, supported by colleagues using sledges and skidoos - it is questionable who is exposed to the most cold exposure, the diver or the supporter? This topic is currently being investigated at Signy. The winter population of staff here is 16, rising in the summer to as much as 25 to 30.

(3) **Faraday** is situated on the west coast of the Antarctic Peninsula. It is a centre for atmospheric science research and meteorology. At the base, summer temperatures range from 0 to +2°C, while winter temperatures range from -2°C down to -20°C.
During the winter months, sea ice forms over the whole area, allowing sledging between the islands. There are normally 11 - 15 staff resident all year round.

(4) **Rothera** is also located on an island just off the coast of the Antarctic peninsula. This is the largest of the bases, with a winter staff of 15 and a summer staff of 70. Rothera is the centre for air operations and is the only British station from which fixed wing, wheeled, aircraft can be operated. The base supports field teams travelling to remote sites. Once a camp has been set up, sledges and skidoos are used for transport. The skidoo is rapidly replacing the dog teams at Rothera.

(5) **Halley** is the most southerly and remote base at a latitude of 75° South, experiencing long periods of total darkness in winter and the midnight sun in summer. The station is situated on the Brunt ice shelf, 12 km from the ice edge where the supply ship unloads stores. This occurs only once a year due to the normally ice-bound status of the Weddell Sea. Air transport to Halley is, however, possible during the summer months using a snow skiway. The winter population of staff is 18, doubling in summer.

AIR OPERATIONS

The first Antarctic aviator was Captain Scott, who transported a tethered balloon from England onboard the Discovery. In 1902, Scott used the balloon to obtain a bird's-eye view from almost 800 feet, south to the Ross Ice Shelf . Occasional pioneering flights in fixed wing aircraft occurred during the late 20's and 30's, supporting early scientific expeditions.

Operations from Rothera are currently undertaken using four twin engined, ski-equipped de Havilland twin otter aircraft. The twin otters have a normal fuel range of 850 km. Under normal operations, only one or two passengers are carried at one time, with a major function being the transport of field equipment and fuel for onward air and field activities.

During the 1994/1995 season a four-engined de Havilland Dash 7 aircraft will be commissioned to extend the working range to 2300 km and the payload to 2270 kg. This aircraft is currently undergoing considerable modification including the fitting of a large cargo door, long-range fuel tanks and an avionics upgrade. It will

give the air unit the ability to carry up to 16 personnel between the Antarctic and the Falkland Islands, considerably reducing travelling times for scientific staff.

Operational support for the field parties has seen a recent significant improvement brought about by the building of a gravel runway at the Rothera research station. This hard airstrip, suitable for wheeled operations, replaces a snow skiway which was 5 kilometres north of Rothera and 275 metres above sea level, where adverse weather conditions frequently restricted air operations. The new facility is a 900 metre long crushed rock airstrip, with a parking site and hangar offset to one side, plus fuel storage tanks.

The air unit is staffed by 6 pilots and 3 aircraft engineers operating during the austral summer from October to March. Each season, after an annual overhaul, the twin otters are flown down from the United Kingdom to Rothera via Greenland and the Americas, a journey taking 11 days and 75 flying hours. Once on site, training flights are undertaken and depots of equipment and supplies taken out to field locations.

The Rothera research base is occupied to full capacity at the start and end of the summer season when research parties are preparing for and returning from the field. This results in periods of heavy aviation traffic, with numerous field projects in locations up to 1500 km distant. Mid season, staff may be required to travel between Rothera and Halley to support the scientific projects. The aircraft are also used for remote sensing, for airborne surveys, and to provide pilotage information to the two British Antarctic Survey research vessels, the Royal Research Ship Bransfield and the Royal Research Ship James Clark Ross.

All of the British Antarctic Survey bases are visited by aircraft, helicopters and ships from the United Kingdom and from other nations, enhancing international co-operation. The air unit thus serves many functions during the summer months.

HAZARDS OF COLD

The personnel who live and work at or from the research stations represent a balance of scientific and support staff. Each year approximately half of the station complement is replaced. The vital continuity of experience and expertise is promoted through those who remain for a second year. Field work requires a self contained unit of skidoo, sledge and tent, food and clothing, scientific and personal gear, a radio for communications and medical equipment. Travel may be across sea, ice or glacier.

Specific hazards which may be encountered include trauma, snow-blindness, carbon monoxide poisoning, disorders caused by caused by altitude or diving, and local and general cold injury. Risk is minimized by thorough preventative measures and procedures.

The climatic hazards of the Antarctic are obvious. Air temperatures are always close to freezing and wind chill will be of huge significance when wind speeds of up to $20ms^{-1}$ are experienced. Exposure to these factors will greatly increase the potential heat

loss from the body, by convection and conduction. However, the intensity of solar radiation is much higher than normal, due to the clear air and high reflectance resulting in relatively high temperatures on surfaces exposed to the summer sun. This advantage is lost at night.

To provide protection against such hazards, each member of staff always travels with a P-bag, containing a lilo, a sheepskin, a sophisticated sleeping bag and bivvy bag. He or she will be issued with boots, gloves and goggles.

Exposure of an individual to such extreme conditions without adequate protection would quickly result in the development of hypothermia - a fall in body temperature to below 35°C. The signs and symptoms of hypothermia are well documented:

- shivering during the early stages, which may diminish with time;
- changes in mood, either apathy or sometimes aggression, often uncharacteristic of the person;
- loss of peripheral pulse due to vasoconstriction and central pooling of blood into the body core; and
- bradycardia, indicating the general slowing of body processes.

The physiological effects of hypothermia are generally given precedence, but they are not the only factors which will affect an individual's chances of survival. Experiments investigating the effects of cold on human performance have shown that, as the body cools, mental performance is impaired. When the body temperature of test subjects was lowered by immersion in cold water, followed by rapid transfer to warm water thereby abolishing the distracting effects of a cold skin, both memory registration and speed of reasoning were impaired (1). Subjects were asked to remember passages containing 15 facts. At a deep body temperature between 34 and 35°C memory registration was significantly affected, with 17 to 43% of recall as compared to the test at normal body temperature. Similarly, the speed of performing double-digit additions and reasoning problems was impaired. For each mental task, the impairment was progressive, and apparent below a deep body temperature of 36°C. Thus, the individual does not have to be hypothermic before his or her mental performance is affected.

This factor may affect the decision-making process, when an emergency situation has to be assessed and sometimes quick responses made. In the remote environment of the Antarctic, any incident is likely to involve a small number of people, albeit well equipped, but in a basic survival situation. The insidious effects of body cooling, just one of the hazards, is perhaps one of the more important factors to be considered, making prevention and protection from exposure so important.

MEDICAL SUPPORT

The four main bases, Halley, Rothera, Faraday and Signy, are each manned by a Medical Officer throughout the year. Prior to journeying south each doctor spends several months at the RGIT Survival Centre where the British Antarctic Survey Medical Unit is based. Specialized training is given in a fields such as general anaesthetics, radiography and diving

medicine. The doctors also take on research projects including relevant subjects such as nutrition, the study of circadian rhythms and medical communications. A database has also been set up to build up a picture of the illness and injuries of personnel working in a remote and isolated site. The database will not only improve information about the patterns of illness and injury, but may in the future give direction as to training needs and perhaps help in the selection of personnel volunteering to go south, both from the point of view of physical fitness and just as important perhaps, from the psychology and personality aspect.

Once on site in the Antarctic, the medical officer will operate from a well stocked surgery. As a back-up, in case of catastrophic damage to a base, an emergency medical box is kept at a site distant from the surgery and general base area. This kit includes a "burns box", plus emergency food and clothing. In the event of an emergency occurring away from base an emergency "grab bag" is maintained at the surgery, to allow the doctor to provide immediate care at a remote field site, prior to transfer back to the base.

As well as training the Medical Officers, the Medical Unit in Aberdeen is also responsible for providing first aid training for all personnel going down to the bases, again with emphasis on topics such as hypothermia.

As a middle tier in the medical support, some staff who will be travelling into the field are given special first aid training. Each field party carries a field medical box. Field staff are therefore trained in the use of medicines, drug, contraindications and injection techniques, similar to the military paramedics.

The personnel working in the Antarctic thus represent a relatively highly trained team should an emergency occur. This is of course essential due to the remote location. The primary aim is to provide full medical care on site. Advances in telemedicine techniques, currently being researched at the RGIT Survival Centre, have greatly improved communications, with the use of satellite telecommunications. This allows rapid contact with the senior medical officer and specialist medical departments in Aberdeen, giving backup to the doctor and first-aiders on site.

It is current policy to treat personnel on base where-ever possible. However, if an evacuation is necessary, then an air evacuation will be mobilised, either to the Port Stanley hospital in the Falklands, to Punta Arenas in Chile, to Montevideo in Uruguay, or Christchurch in New Zealand. Depending upon the time of year and location this may well require a series of flights and international co-operation.

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Evaluation of Life Support Equipment during an Unsupported North Pole Expedition

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Summary

This paper presents practical experience with the following life support equipment used during an unsupported North Pole expedition in 1992: Clothing, sleeping bag with vapour barrier inner liner, a high efficiency cooking gear for melting water, and freeze dried food with 70 % of the energy from fat.

Introduction

On the 1st of March 1992 three Norwegians left Severnaya Zemlya, Siberia, heading for the North Pole. Ward Hunt on Ellesmere Island, Canada was the final goal if ice conditions permitted (fig 1). All team members were 27 years old, with a military background from the Norwegian Special Forces. The expedition was planned to be unsupported, in the sense that all equipment and food needed for reaching the North Pole was pulled in sleds by the team members. Each sled weighed 150 kg at the start, 110 kg of which was fuel and food. The sleds were designed to be used as canoes for crossing open water. Skies were used whenever possible. An Argos one-way satellite radio for relaying simple messages was brought along.

The North Pole was reached on May 12th. Due to very extensive break-up of the ice, the team was forced to discontinue the march towards Canada on June 4th. By then, they had walked about 1.400 km. The Canadian Twin Otter pick-up plane reached them about 24 hours after they had transmitted the radio message.

Environmental conditions

Temperatures varied from -4 to -54°C, with an average of -30°C. There was 24 hours daylight and midnight sun throughout the expedition, except for the first 14 days. There was an almost equal number of sunny and overcast days. A heavy snowfall, one meter in a week, occurred shortly before the Pole was reached. Winds varied from almost quiet to storm, with a moderate breeze predominating. During the last 3 weeks of the expedition a strong steady wind was blowing the team 20 km in the wrong direction every day. There was higher temperature, less ice and more open water during the expedition than average for the March-June period. Crossing open water (1-50 m) was neccessary from 1 to more than 30 times a day. The team occasionally encountered larger cracks in the ice and had to walk around. The first 30 days they crossed a 200 km wide area of pack ice with ridges and ice towers up to 20 m height. Pack ice and open water represented about 30 % of the total distance, the other 70 % being relatively flat ice.

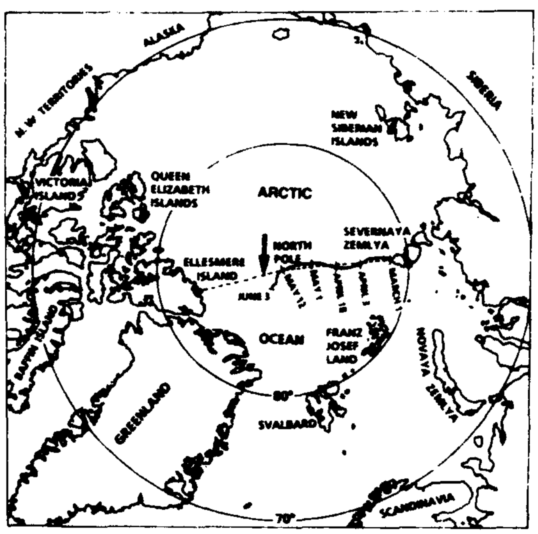

Figure 1. Planned and actual routes for the expedition

Work / Rest Cycle

After breakfast and break of camp the team normally walked for one hour followed by a ten minute break, continuing this schedule for 9 or 10 hours a day, and covering a distance of 5-25 km depending on ice conditions. During the short breaks they had water, chocolate and cereal mixed with fat. The main meal was prepared after a new camp had been established. Time for breaking camp depended on weather and ice conditions. In the latter part of the expedition they often found

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it advantagous to walk at night, with the midnight sun behind them.

Clothing

Presently most polar expeditions select clothing material based on synthetic fibers, however in accordance with Norwegian tradition the team mainly used the natural fibers wool and cotton (fig 2).

All team members used wool underwear next to the skin, based on personal experience that wool retains insulating properties better than synthetic material when getting wet and dirty. Due to the strict weight limitations they used the same underwear during the entire expedition. Wool will retain more humidity than synthetic fibers. This was not a problem while walking, due to the heat production induced by exercise.

When comparing wool to clothing based on synthetic fibers during exercise trials in a cold storage facility (-42°C) prior to the expedition, the team members became more thirsty and seemed to get dehydrated faster in synthetic clothing. The more efficient transfer of humidity by the synthetic fibers might create a dryer microclimate next to the skin and possibly enhanced water loss by perspiration.

The teams prior experience with Gore-Tex material in the Arctic had been unsatisfactory. Ice tends to form between the layers, making the material almost impermeable. In severe cold the material gets brittle and the membrane easily cracks. The only Gore-Tex product that was brought along, was extra windproof mittens. In temperatures below -15°C they got stiff and lumpy with reduced transfer of humidity.

Windbreakers (anoraks) were produced for the expedition by Norrøna Sport A/S, Asker, Norway. All garments were of equal design, but manufactured in cotton for one team member and in an experimental, synthetic microfiber for the two others. Cotton worked best in severely cold conditions, and had a better transfer of humidity. The microfiber was better in milder, more wet conditions as it did not absorb so much humidity and dried quicker.

Trousers were made of a loden type of fabric ("Norrøna Loden trousers"), known as "vadmel" in the Nordic countries, a traditional rough, wollen cloth used for outer garments since the fourteenth century. Fridtjof Nansen and other polar explorers successfully used the material 100 years ago. A special type of shaggy wool is woven very tightly and shrunk in a washing process. It works extremely well in very cold conditions. Even during the coldest period of the expedition (- 54°C), two pairs of thin wool underwear and the thick loden trousers were sufficient. Loden does not function well in mild, wet conditions. In strong wind, the team members put windproof microfiber pants on top.

The footwear (fig 3) was based on eskimo tradition, mukluks made of seal and polar bear skin. They were waterproof, insulated well and were very strong, as each team member walked in the same pair for the entire 100 days of the trip. Two thick, wool felt inserts were put in the mukluks to reduce heat loss to the ground. A thin polypropylen sock was worn next to the skin, and one thin and two thick woolen socks. A vapour barrier sock was placed between the polypropylen sock and the woolen socks, to prevent foot perspiration from freezing up in the wool socks. This arrangement functioned very well. The inserts, however, could have been even thicker for better insulation to the ground.

The mukluks were attached to the skies by a special leather strap binding, formed like a sandal. Each team member brought one pair of skies, Telemark mountain skies of fiberglass/wooden core with steel edges ("Telemark Sondre", Åsnes A/S, Straumsnes, Norway). A synthetic fur, ("Skifeller", Åsnes A/S), was glued under the skies to prevent slipping.

Protection of hands and fingers is difficult. The team used windproof mittens of microfiber or Gore-Tex, and innermitts of wool or synthetic fleece, but found that too much ice was forming in the innermitts (fig 3).

Head and face were protected by a nylon/hollofil/pertex cap with ear flaps, a neopren cold weather facemask, sun goggles and a windproof, fur-lined hood. In addition the facial skin was protected by fatty creams (goose fat and waterfree vaseline).

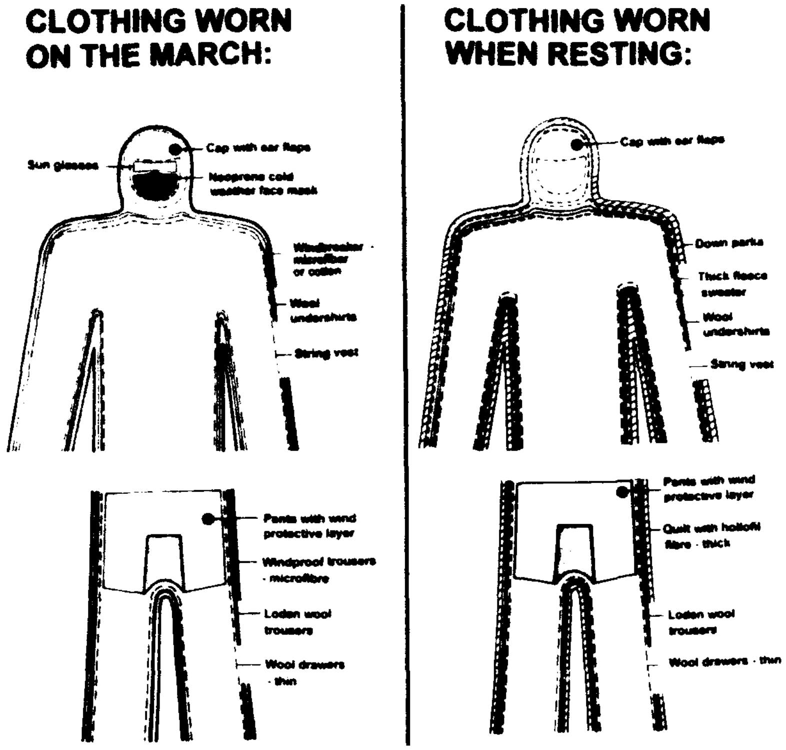
During the breaks they put on a down parka. In the camp area they wore a thick synthetic, fleece sweater, and thick pants of hollofil fiber, in addition to the parka (fig 2). In the sleeping bags only the woolen underwear was used.

All team members fell through the ice a few times. This was not nearly as dramatic as had been expected. They quickly emptied the mukluks and continued marching. The underwear was dried by body heat, and ice forming in the outer layers of the clothing could be shaken off. The mukluks however would remain very stiff for several days depending on weather conditions.

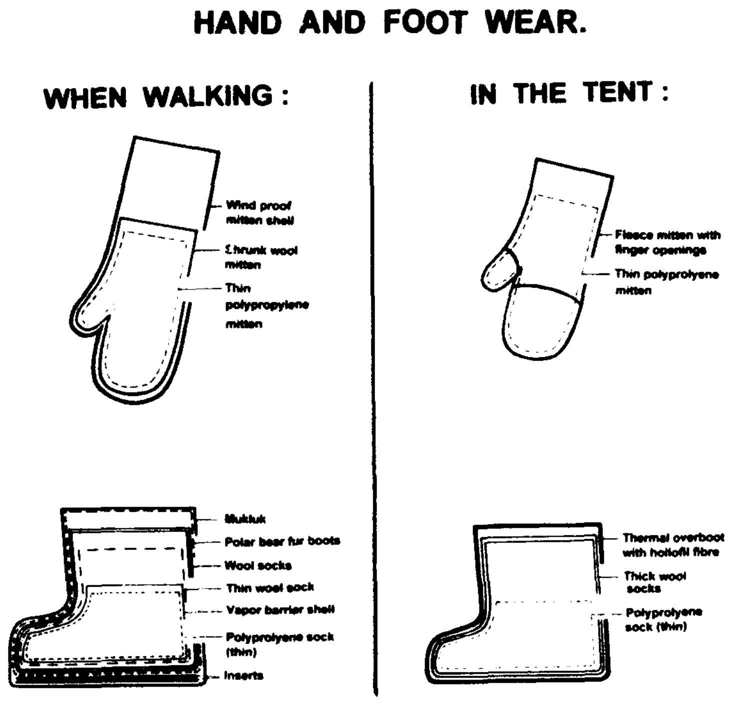
A few cases of superficial frostbite were experienced, but no permanent cold injury.

Sleep

Good sleeping quality is extremely important for the successful outcome of an expedition of this character. It has been the first authors' experience that the army often does not put enough priority on sleeping. Most military exercises are too short for the detrimental effects of sleep deprivation to be fully experienced. Large reductions in levels of testosterone and other anabolic steroids have been shown during stressful exercises and lack of sleep (Opstad,1992). A catabolic effect on muscle



Figur 2. Clothing worn while marching and resting



Figur 3. Hand and foot wear

tissue is not desirable in a strenous expedition lasting several months. Since production of these hormones is at its peak during sleep, the provision of good sleeping conditions can partly prevent the fall (Opstad, 1993).

Great care was taken in making the campsites as comfortable as possible. The tent was of a tunnel type, manufactured for the expedition by Helsport A/S, Melhus, Norway. The tent was unheated, apart from excess heat from the occupants and from cooking. Three 1.3 cm thick closed-cell ethylene vinyl acetate foam mattresses with an air trapping ridge pattern were used as insulation under the sleeping bag ("Ridge Rest", Cascade Designs Inc, Seattle, USA). The sleeping bags were placed close together. The sleeping bags (fig 4) were made of the synthetic fiber hollofil ("Alaska North Pole", Isolett A/S, Trondheim, Norway), individually fitted by the factory in order to make the bag surface area as small as possible. A polyamid based fleece cover was fittet around the sleeping bag. Frost forming in the fleece could easily be shaken off. The sleeping bags were never used for drying clothes. This practice will deteriorate sleeping quality. Wet clothes dried up when the team members put them on and started marching. In addition, the main hot meal was always consumed just prior to sleeping, thus heating the body core and taking advantage of metabolic and digestive heat production.

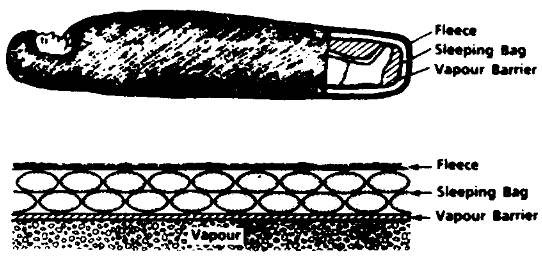


Figure 4. Sleeping bag with synthetic fleece cover and vapour barrier inner liner

A common problem when the temperatures are below - 15°C, is the formation of ice in the sleeping bag, caused by the perspiration of water during the night. The fluid evaporates near the skin surface, but will condensate and freeze in the outer layers of the sleeping bag where temperatures are below 0°C. This will reduce the insulation of the sleeping bag and make it heavier to carry.

Based on favorable trials in a cold storage facility (-42°C) with a vapour barrier inner liner inside the sleeping bag, this technique was successfully adopted on the expedition (fig 4). No accumulation of ice occured in the sleeping bag, apart from the frost that was brushed and shaken of the fleece cover every morning. The liner was made of polyurethan coated nylon and manufactured by Isolett A/S.

Testing of sleeping bags at the Norwegian Defence Research Establishment has indicated that at - 20°C about 50 % of perspired water vapour will condensate and partly freeze in the outer layers of a standard sleeping bag. When the polyurethan inner liner and the fleece cover are used, only 10 % of perspired fluid will accumulate within the layers of the sleeping bag (Martini, 93).

We believe that this was one of the few polar expeditions without complaints of feeling cold during sleep. Even though the water could not evaporate, the moisture was absorbed in the underwear and sleeping was not uncomfortable. The moisture stayed in the underwear and quickly froze in the morning when they got out of the sleeping bags. Much of the ice could then be removed by shaking the garments, without taking them off.

Water and food

Preventing dehydration was a major concern, and the team members were drinking 4.5 - 5 liters of water a day, including the water added for breakfast and dinner. Respiratory water loss was probably high due to exercise increased ventilation and the low water content of the cold air. Dehydration may lead to increased blood viscosity and slower peripheral circulation. The extremely high fat content of diet composed for the expedition might further increase blood viscosity.

A protective, neoprene face mask with a respiratory filter made for asmathics was used when temperatures were very low. The filter reduces respiratory water loss by a water exchange mechanism between expired and inspired air. The mask also works as a heat exchanger, thus reducing respiratory heat loss, and saving energy. The filter is based on a stainless steel mesh ("Jonaset", Suomen Oy, Helsinki, Finland).

All team members seemed to have a high urine production and a somewhat reduced bladder control with frequent urinations. This was believed to be partly due to the cold and partly to the mechanical irritation of the bladder by the sled pulling-belt.

Melting and heating water was done by a prototype high efficiency cooking gear, developed by the Norwegian Defence Research Establishment (fig 5). The device consists of a simple burner working on unleaded gasoline (pure heptane was used), and a pot for cooking and melting ice, placed inside a container,

thermally insulated by a ceramic material. The container directs the hot gases from the burner over the entire surface of the pot. The efficiency was further improved by making the outer surface of the pot and the inner surface of the container black by anodizing. The obtained efficiency was about 70 %, versus 47% for the pot without the container, thus reducing fuel consumption by about 1/3 and shortening the time requried for melting and heating the water by the same factor (Oftedal, 1992).

COOKING GEAR WITH HIGH THERMAL EFFICIENCY

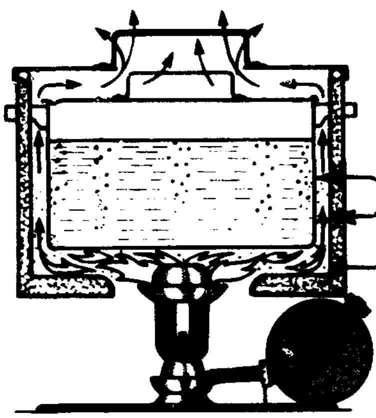


Figure 5. High efficiency cooking gear

The cooking gear was normally used at breakfast and dinner, and thermos bottles were filled with hot water for the breaks. About 5 liters of water were melted per person per day, using about 180 ml fuel per person per day when temperatures were - 40°C, and about 130 ml at temperatures around - 10 °C. Each man had brought 200 ml of fuel per day, and there was a large surplus of fuel when the expedition was discontinued. The team members found the device very useful, reliable, robust and safe to operate. It was lightweight with an additional large weight saving due to the high fuel efficiency. The outer surface of the container could safely be touched, and the lid was often used for drying socks, sole inserts and mittens.

All team members had gained about 10 kg in body weight before starting, due to deliberate overeating of a diet rich in fat for 6 months prior to the expedition. Each member lost from 5 to 10 kg during the 100 days of marching. The diet provided about 6000 kcal a day (Table 1). Due to the severe weight limitations an extremely high lipid content was neccesary (fat providing 9 kcal/g, versus 4 kcal/g for carbohydrates and proteins). 70% of the energy came from fat, while 65% was the highest that had been tried on earlier expeditions. The fat was a mixture of 60 % soya oil and 40 % medium chain triglycerid (MCT). Carbohydrates provided 1000-1200 kcal per day.

Table 1. Composition of daily portions of freeze dried food

	Energy (Kcal)	Weight in grams			
		Total weight	Protein	Fat	Carbo-hydrate
Breakfast	1315	222	11	136	75
Lunch	3030	475	18	336	117
Dinner	1665	278	38	183	57
Total	6010	965	67	655	249

Fat is MCT:Soya 1:1. Vitamins and trace elements were added. Fiber 30 g. Water content 9 g. Plastic bags 35g

Protein content was less than 1 g per kg bodyweight per day. The diet composition reduced the need for water, due to generation of metabolic water by fat and carbohydrate oxydation, and low water requirement for urea excretion. The diet also contained fibers, vitamins and minerals, with an addition of vitamins of the C, E and B-group.

All food was freeze dried and vacuum packed in daily portions. Weight of the plastic bag was about 3 % of each portion. The breakfast consisted of cereal, raisins, sugar and powdered cream mixed with hot water. During the breaks they ate cereal, fat, raisins and chocolate. Dinner was the highlight of the day and was made with special care. The basis was fat, mashed potatoes, carrots, spices and hot water. Beef, fish or corned beef were added, creating some variation in the rather monotonous menu.

Lack of experience with extended use of a diet like this was a major element of uncertainty. All team members found the diet satisfactory. No one got too terribly bored with the menu or had fantasies of food orgies as many other expeditions have experienced.

Conclusions

Aided by the described equipment and food the team members completed — and enjoyed — their 1.400 km march in extremely difficult ice conditions and temperatures down to - 54°C. After 100 days on the ice they still had supplies for at least another month of survival, in contrast to the friendly, civilian pilot who came to pick

them up in jeans and a short jacket, dressed for the cockpit, not his destination.

Acknowledgements

The support of the following equipment and food manufactures are greatly appriciated:

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PREDICTION OF SURVIVAL TIMES ON LAND IN A COLD CLIMATE

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SUMMARY

Eight subjects were exposed to three different combinations of air temperature and windspeed for two hours in a climatic chamber. Changes in core temperature, surface temperatures and heat flux, and metabolic rate were recorded during the exposure. The results obtained were compared with the predictions derived from a sophisticated computer model of human thermoregulation and heat exchange. Conclusions about the factors responsible for the rate of body cooling in air, and the causes of the wide range of variability observed are discussed. The problems of predicting survival times on land for a diverse population are considered, and possible solutions suggested.

1 INTRODUCTION

An increasing amount of military flying is taking place over land which has a cold climate. Aircrew having to abandon their aircraft over such terrain face the hazards of hypothermia and cold injury during their attempts to survive. In addition, the large distances and unpredictable climates of these areas mean that rescue times may be much greater than in temperate regions.

Ideally, aircrew would be provided with sufficient extra clothing and survival equipment in their personal survival packs to ensure that they would not become hypothermic. However, space is limited in survival packs, particularly in ejection seat aircraft, and packs may be lost during aircraft abandonment. Consequently, aircrew may have to survive wearing only the clothing worn in the cockpit. It is thus desirable to be able to provide advice on the amount of clothing that should be worn to prevent heat loss in the environments which may be encountered.

The rate of body cooling on land is determined by a large number of factors. These include air temperature, windspeed, humidity, radiant heat exchange, the amount and type of clothing worn, and the responses of the individual. The latter include metabolic and vasomotor responses, which may be influenced by the state of fitness, nutrition and body composition. Behavioural responses, such as exercise and the provision of fire and shelter, are major determinants of body cooling, and it is therefore necessary to consider the worst case of the injured or exhausted survivor who is unable to do anything to improve his situation.

It is possible to predict the rate of core cooling of passive individuals exposed to different environmental conditions and wearing different clothing by human experimentation. Subjects may be exposed to a variety of conditions, and their thermal responses measured. However, due to ethical and safety considerations the exposures must be limited in time or severity to ensure that the core temperature does not fall below a predetermined safe level, and responses outside the experimental range must be surmised.

A more versatile approach is to utilise a mathematical model of human thermoregulation. Many of these have been developed, and have reached a high level of sophistication (1). Models have been used to good effect to predict survival times for the simpler case of immersion in water (2), and to provide guidelines on the amount of clothing which should be worn under an immersion suit to achieve survival times in excess of predicted rescue times for given sea temperatures.

The great advantage of adopting the modelling approach is that it allows predictions well outside the envelope considered ethical for human experiments. However, without adequate validation of such models by means of comparison with human data, the results must be treated with the utmost caution.

A model could be considered to be reliable if it was able to reproduce the changes in core temperature observed in subjects exposed to the conditions under consideration. However, this has the same limitations as using human data alone, i.e. the predicted values outside the range of the human exposure cannot be verified by extrapolation. A better approach is to attempt to validate the component parts of the model in a set of less severe conditions, by measuring, for example, surface heat flux and metabolic rate in addition to core temperature (3). If it can be shown that all the components are in accordance with observations in the narrower range of conditions, more weight can be given to the predictions which lie outside the verifiable range.

This paper describes an experiment where subjects were exposed to cold air and their thermal and metabolic responses were recorded. The results are analysed in the light of model predictions, and the factors which are responsible for individual variation, and which must therefore be considered in the construction of an adequate model, are discussed.

2 METHODS

Subjects
The subjects for the experiment were 8 healthy male volunteers (subject data shown in Table 1), who had the experimental procedure fully explained to them, and signed consent forms in accordance with the requirements of the RAF Institute of Aviation Medicine Ethics Committee. They had not recently been exposed to cold stress. They were medically inspected prior to undergoing experimentation, including a 12-lead electrocardiogram.

Experimental design
Each subject underwent exposures to cold air in a climatic chamber not exceeding 2 hours in duration, during which time rectal temperature, skin and clothing temperatures and heat flux, heart rate and metabolic rate were measured. The environmental conditions were maintained as follows:-

Condition 1	-12.5°C, Windspeed < 0.8 m/s
Condition 2	-12.5°C, Windspeed 5.2 ± 1 m/s
Condition 3	-26.5°C, Windspeed < 0.8 m/s

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

TABLE 1

Subject Data

SUBJECT	AGE	HEIGHT(m)	WEIGHT(KG)	MWST*(mm)	%BODY FAT**
AC	41	1.63	59.45	13.6	21.7
CM	21	1.88	90.09	14.1	19.9
GM	27	1.81	81.49	9.7	16.2
HD	41	1.77	78.39	11.3	10.8
JM	34	1.85	81.43	14.3	23.4
LS	20	1.70	53.09	6.3	13.6
WC	32	1.76	121.21	30.4	30.7
DL	25	1.85	106.69	14.8	26.8

* Mean Weighted Skinfold Thickness calculated from MWST = 0.2 x Biceps + 0.2 x Triceps + 0.35 x Subscapular + 0.25 x Suprailiac skinfold thicknesses.

** Derived from whole body impedance measurement.

Each subject was exposed to each of the 3 conditions, with the exception of subject DL who took part in one exposure only. All subjects were exposed to condition 1 first, and the subsequent order of conditions was randomised. Each subject had at least 48 hours between exposures.

Instrumentation
The subjects were instrumented at 0830h in a room with the air temperature maintained at 22°C, having eaten a light breakfast, and abstained from tea, coffee, alcohol and tobacco from midnight. Prior to instrumentation, the subjects' height, nude weight (Mettler ID3 balance), and skin-fold thickness at 4 sites were measured. An estimation of the percentage body fat content of each subject was made by measuring whole-body electrical impedance (Tanita Body Fat Analyser). The subject inserted a series 400 rectal thermistor to 10cm past the anal margin and a recording of his rectal temperature was made. Nine heat-flux transducer disks (Hamburg Associates Part No HF147-197), recalibrated by the method described by Sowood (4), were affixed to the skin using double-sided adhesive film and thermally conducting paste (Ecotherm TC4) at the sites detailed in Table 2, which were adapted from Bell et al (5) to incorporate a forehead site. Standard ECG electrodes (S&W Medico Teknik) were affixed to the chest, and the subject then dressed in a standard clothing assembly consisting of cotton long-johns, cotton roll-neck shirt, Mk 14 RAF flying coverall, 2 pairs of terryloop socks, "Mukluk" foot assemblies, comprising a felt inner boot, mesh sole and nylon outer boot, knitted inner gloves, knitted mittens, immersion mittens, a balaclava hood and an RAF aircrew survival hood. The insulation of this clothing assembly was previously determined to be 1.89 clo, measured using a thermal manikin (Cord TIM2) in still air. A further 9 heat-flux transducers were affixed to the clothing surface at sites corresponding to those on the skin.

Measurement
Following instrumentation, the subject was seated at rest in a thermally neutral environment and a further reading of rectal temperature was noted. He breathed for 10 minutes through an open respiratory circuit comprising a dry-gas meter (Parkinson-Cowan), wide-bore tubing and one-way valve box, and a mixing box from which samples of dried expired air were passed to an oxygen analyser (Servomex 540A) and a carbon dioxide analyser (P K Morgan). The dry-gas meter was fitted with a transducer to give a digital readout of inspired minute volume (Hewlett-Packard respiratory integrator); the output of the gas analysers was to a two-channel pen chart recorder, the response of which was calibrated against standard gases (BOC) at the beginning, during, and at the end of each experiment. The resting metabolic rate was calculated over the second 5-minute period by application of the Weir formula (6).

TABLE 2

Siting of heat-flux transducers

Disc No.	Position
1	Mid-point of right biceps
2	Forehead
3	Right lateral forearm
4	Right anterior abdomen
5	Right inferior scapular angle
6	Right posterior iliac crest
7	Right posterior thigh
8	Right anterior thigh
9	Right medial gastrocnemius

The subject then entered the pre-conditioned climatic chamber and was seated, semi-reclining and facing into the airflow, in a hammock-type seat, designed to allow maximum exposure of the subject to the air. He breathed continuously through the respiratory circuit described above, and the average metabolic rate over the last 5 minutes of every 15 minute period was calculated. The outputs of the rectal temperature probe, heat-flux transducers and ECG leads were led to an automatic data-logger (RAF IAM Systems Engineering), sampled every five minutes and stored on magnetic disc (BBC micro computer). The ECG and clinical condition of the subject were continually monitored throughout the experiment. The exposure to the cold environment was terminated at the request of the subject or the discretion of the supervising medical

officer, if the rectal temperature fell below 35°C, or after 2 hours. The subject was then undressed and rewarmed by immersion in stirred water at 40°C while rectal temperature continued to be monitored, until it returned to within 0.5°C of its initial value.

Analysis of Data
Subject DL only took part in one trial, and was therefore excluded from the analysis of results to maintain balance. Mean values for the temperature and heat flux of the skin and clothing surface were calculated from the nine individual measurements using an area-based weighting derived from Hayes et al (7). If data was lost from an individual heat flux transducer, as was the case in a small number of runs, its value was estimated by linear regression on the complete data set. Initially, analysis of variance was undertaken considering the factors of time and condition (fixed effects), and subject (random effect). To simplify the analysis and interpretation of the changes of measures with time, the time course was expressed either as an exponential decay, or a linear trend. Analysis of variance was then applied to the parameters of the fitted function, removing time as a factor. The exponential trend was used for surface temperatures and heat flux, while the linear trend was applied to rectal temperature. In the case of the exponential decay, the final level was regarded as the key parameter.

Body Composition
Subjects were divided into 2 "fatness" groups (GF) on the basis of their mean weighted skinfold thickness, with the division at an MWST of 11.5mm, in an attempt to investigate the large inter-subject variability in thermal response. In addition, since metabolic rate was predicted to be affected by body mass, the subjects were also split into 2 groups (GW) by weight (see Table 3).

TABLE 3

	FAT GROUP GF	WEIGHT GROUP GW
GROUP 1	"Thinner"	"Lighter"
GROUP 2	"Fatter"	"Heavier"

The actual allocation of subjects to these groups is shown in Table 4.

TABLE 4

Allocation of Subjects to Fatness and Weight Groups

SUBJECT	GF	GW
LS	1	1
GM	1	2
HD	1	2
AC	2	1
JM	2	2
CM	2	2
WC	2	2

Mathematical Modelling
The mathematical model used in this study was the Texas model, as described by Wissler (8, 9), modified to give a better representation of counter-current heat exchange between veins and arteries, and an improved representation of body composition (2). Model simulations of 2 hours duration were run using the parameters of each individual exposure (the weight and mean weighted skinfold thickness of each subject, the temperature and the windspeed), and a single clothing thickness yielding a value of 1 clo (without the air boundary layer) which approximates to the insulation worn. The simulated physiological parameters were then compared with those actually recorded in the climatic chamber, at 5 minute intervals in the case of temperatures and heat fluxes, and at 15 minute intervals for metabolic rate, using analysis of variance. Since there was a high degree of correlation between successive deviations of observed and predicted values for rectal temperature, key comparisons were made by comparing the observed and simulated gradients of temperature with time. To reduce bias due to subjects failing to complete the entire 2 hour exposure, the comparison of data was truncated at 90 minutes.

3 RESULTS

Rectal Temperature
Figure 1 shows the rectal temperatures of all the subjects throughout their exposures to the 3 conditions. In all cases the final temperature is less than its starting value, although it is apparent that the rate of fall of rectal temperature shows a large degree of variation between subjects. There is a difference between the fatness groups ($p < 0.01$), but no evidence for a difference between the 3 conditions. Fitting a linear model to the rates of fall of core temperature and declaring time as a linear trend yields similar conclusions. Figure 2 shows the mean rectal temperatures for the 2 fatness groups, together with the values predicted by the computer model. There were no demonstrable systematic variations between the observed and simulated rectal temperatures, although there were clearly random deviations associated with the comparison of individual subject responses. Dividing the population into 2 groups on the basis of mean weighted skinfold thickness explains 69% of the variation in observed mean rectal temperature between subjects over 90 minutes, and 80% of the variation in downward trend. The corresponding values for the computer simulations were 66% and 59% respectively. It is clear that the model is simulating gross changes in core temperature with time and condition reasonably reliably, and that a simple division of the population based on skinfold thickness allows prediction of a large degree of the observed variation in response.

Metabolic Rate
The observed and simulated values for metabolic rate are shown in Figure 3. Metabolic rate rises with time in all three conditions. Analysis of variance shows that for the observed values, there is a difference between condition 1 and the other conditions ($p < 0.001$), and that there is also a significant difference between the 2 weight groups, GW1 and GW2 ($p < 0.05$), in line with the expectation that metabolic rate would be higher in heavier individuals. No significant difference could be demonstrated between the 2 fatness groups.

Table 5 details the mean observed and simulated values. Analysis of the difference between them shows that the simulated metabolic rate exceeds the observed in condition 1 ($p < 0.05$), but does not differ in the other conditions. The general shape of the rise with time is apparently simulated adequately.

Mean Weighted Skin Temperature
Parametric investigation of mean weighted skin temperature, as described above, yields a good exponential description, with a clear effect of condition ($p < 0.001$). The observed and simulated values are

TABLE 5

Mean observed and simulated metabolic rates (watts)

TIME (MINS)	COND 1		COND 2		COND 3	
	OBS	SIM	OBS	SIM	OBS	SIM
0	95.8	111.2	96.1	111.2	85.0	111.2
15	99.2	144.5	178.8	212.0	143.2	173.9
30	118.4	177.1	202.8	213.0	172.2	202.4
45	140.7	193.7	243.4	240.8	199.5	233.2
60	144.7	201.5	281.1	254.0	241.2	254.4
75	166.4	214.0	300.6	271.2	274.7	274.4
90	196.9	225.5	298.9	285.3	352.9	289.3

TABLE 6

Mean Terminal Clothing Temperature (°C)

CONDITION	GP1		GP2	
	OBS	SIM	OBS	SIM
1	8.53	1.83	8.53	1.11
2	-0.24	-6.89	0.38	-7.22
3	2.97	-4.24	4.09	-8.07

plotted in Figure 4. Consideration of the equilibrium temperatures revealed that the simulated values were less than the observed results ($p < 0.01$), and that this difference was itself different between conditions ($p < 0.05$). There was no evidence of a difference between fatness groups.

Mean Weighted Skin Heat Flux

Mean weighted skin heat flux generally follows the same exponential pattern as the skin temperature, with similar effects of condition, but in this case there is a difference between fatness groups ($p < 0.01$), thinner subjects losing more heat from the skin than fatter ones.

Mean Weighted Clothing Surface Temperature

The temperatures recorded at the clothing surface at the abdominal and anterior thigh sites varied considerably during trials, due to the posture of the arms adopted by the subjects, which was deliberately unconstrained. To compensate for this in the calculation, these values were replaced by those for the lower back and posterior thigh, which yields a fair exponential description, and no significant effect of fatness group. However, this approach is probably not justified due to the semi-reclining posture of the subject, with its inherent asymmetry of boundary layer insulation, which would be expected to produce higher temperatures anteriorly than posteriorly, particularly in the conditions without wind.

Consideration of the single site on the upper back, which is unlikely to be affected by posture, yields a small effect of fatness group ($p < 0.1$) in the anticipated direction, i.e. the thinner individuals exhibit higher temperatures. However, little can be deduced from consideration of a single site, particularly one where the capacity for vasoregulation is limited.

The observed and simulated equilibrium temperatures are displayed in Table 6. The observed temperatures are considerably higher than the simulated values ($p < 0.01$), and this difference is variable between conditions ($p < 0.05$). There is no evidence of a difference between fatness groups.

Mean Weighted Clothing Heat Flux

Analysis of variance on the terminal clothing heat flux data shows no evidence of a difference between conditions or fatness groups. Figure 5 demonstrates the computer simulations, which are higher than the observed values ($p < 0.05$), with no evidence of a difference in model accuracy between conditions or fatness groups.

4 DISCUSSION

Providing advice on the amount of insulative clothing which should be worn by an aviator flying over a cold land-mass will inevitably be a compromise. The demand for adequate thermal protection against the harshest climatic conditions likely to be encountered in the rare event of aircraft abandonment, which most probably would require thermally stressful clothing of extreme bulk, is in conflict with the desire for thermal and physical comfort in the cockpit for the performance of the primary flying task. The range of environmental conditions which may be experienced under the flight path of a modern military aircraft in the course of a single sortie may be extremely wide, and it is unrealistic to attempt to dress aircrew for unaided survival in all possible scenarios. Thus, when considering "dress to survive" advice, it is crucial to state a specific aim, and delineate the performance expected of clothing assemblies in terms of the

environment.

The issue is further clouded by the inherent variability of response of a diverse population of individuals exposed to any physiological stressor. This study has clearly demonstrated that exposure of even a small group of anthropometrically diverse subjects to a controlled degree of cold stress will produce changes in core temperature ranging from negligible decreases to precipitous falls which, if unchecked, would be rapidly fatal. Clearly, it is desirable to attempt to quantify this variability, and, if possible, to predict the response of individuals in terms of measurable physical parameters.

The most obvious characteristics of an individual which could be expected to influence his heat exchange with the environment are his size and body composition, and it has long been recognised that the fatness of an individual will have a profound effect on his rate of cooling (12), and also on his metabolic response to cold stress (13). Height and weight are easy to measure, but the insulation afforded by the subcutaneous tissues, principally fat, is much harder to quantify. Traditionally the method employed has been the one used in this study, *viz.* measurement of skin-fold thickness at a variety of sites using callipers, and deducing a mean value with appropriate weighting factors. The technique has been shown to produce values which correlate well with other methods, such as under-water weighing, ultrasonography and magnetic resonance imaging, but it is a very user-dependent technique, and considerable variation in measurement can be produced by different operators (14). More recently, whole-body electrical impedance has been used as a measure of body fat content, but the results obtained are dependent on the hydration status of the individual and the technique requires further investigation.

This study has shown that a large proportion (up to 80%) of the variability in the rate of fall of core temperature in the conditions studied may be accounted for in terms of body composition, simply by dividing the subjects into two groups on the basis of their mean weighted skinfold thickness. This is obviously of great significance if meaningful predictions as to rate of cooling are to be made for diverse populations. It is reassuring that the version of the Texas model used in this study produces predictive results which show good concordance with the actual results of the human experiments, when the same division into two fatness groups is made.

A number of problems remain, however. This study fails to address the issue of intra-individual consistency of response, since each subject was exposed to each condition once only. While anthropometric considerations are able to account for a proportion of the variability seen between subjects, it remains unclear as to the spread of response within each subject. Certainly a variety of factors can alter the metabolic response of an individual to a cold stimulus, including his state of nutrition, physical fitness and level of exhaustion, and his emotional state, all of which are likely to vary from time to time. He will also certainly exhibit the randomness of response that is characteristic of biological systems, and which, without the inclusion of stochastic elements, a mathematical model will not simulate. This inherent variability of response will compound any divergence between model predictions and physiological reality.

Given that the response of individuals will vary, even after the effects of body morphology have been taken into account, and that even the best model will never be completely accurate in its predictions, one is then faced with the problem of determining at what level of anthropometry survival curves should be drawn. If a single measure of morphology were the only factor determining the thermal response of an individual to a given set of environmental circumstances, one could determine a predicted cooling curve for, say, the 10th percentile of the population under consideration (which of course for aircrew may not be the same as for the general population), and have a high degree of certainty that the responses of 90% of the population would indeed lie above the curve. However, with a significant degree of individual variation, it could well be that a much higher number of responses will lie below the curve than the predicted 10%. The safety margin may be improved by quoting curves for smaller individuals, e.g. the 5th or 3rd percentiles, but if these values are being used to determine the required insulation of flying clothing, one will then be imposing a large and unnecessary thermal load during flight operations on the larger members of the population. Linking clothing recommendations to individual anthropometry is one way around this issue, and while the actual level at which survival curves are quoted is more a matter of philosophy than physiology, it is important to appreciate the lack of precision that is inherent in attempting to predict the behaviour of biological systems.

Bearing these provisos in mind, we may consider how well placed we are to make useful predictions of survival times for the downed airman. This study utilised a modified version of the widely used Texas model of thermoregulation, and there is little doubt that it is providing a reasonable estimate of the behaviour of rectal temperature over the first 90 minutes of exposure to the conditions under consideration. It also handles the variation attributable to fatness with a reasonable degree of accuracy.

The model handles some of the other parameters less well, which casts doubts upon the reliance that may be placed on its predictions outside the envelope of validation. While metabolic rate is predicted well in conditions 2 and 3, it is not simulated correctly in condition 1, and thus heat balance is not modelled correctly in this case. However, the model is a closed loop system which is homeostatic, and this is likely to help it get close to observed values for controlled variables such as rectal temperature.

The agreement between observed and predicted values for skin temperature is poor. There are a number of possible reasons for this. There were technical difficulties with some of the surface transducer sites, due to subject posture, which may have produced errors in the observed results. It may be that there is a genuine inadequacy in the model in this area, although this is unlikely in view of its performance in other respects. The most likely explanation is that the representation of the clothing assembly in this particular simulation is too crude. The clothing was modelled as a single layer of wind-resistant insulation over the entire body, giving an insulation of 1 clo, designed to approximate to the value determined for the actual assembly by manikin measurement. However, consideration of Table 7 shows that in condition 2, where wind was present, there is poor concordance between the observed skin and clothing heat flux data. This is due to wind penetrating the clothing assembly, altering its intrinsic insulation and promoting convective cooling within it; certainly the interactions of heat exchange within the clothing are more complex than the model is predicting. The model has the capacity to handle more involved clothing assemblies,

TABLE 7

Mean Terminal Skin and Clothing Heat Flux

COND	SKIN HF (W/m^2)	CLOTHING HF (W/m^2)
1	101.1	109.8
2	174.0	136.0
3	136.2	134.5

and this is an avenue for further work.

A further point of interest demonstrated in Table 7 is that consideration of the values for skin heat flux reveals a large difference in the amount of heat lost in condition 2 compared to condition 3 ($p < 0.001$), although the Equivalent Chill Temperatures of the 2 conditions, as derived from Siple and Passel (13), are in fact very similar. This is a useful demonstration of the well-recognised fact that the Wind Chill Index, while useful for predicting the effect of wind on the cooling of exposed flesh, is not an appropriate tool for predicting total heat loss from clothed individuals (14).

A potential problem with the clothing assembly used in this study concerns the distribution of insulation over the body. Rather than being uniform, there was an excess of insulation over the hands, feet and head. This was deliberately arranged to promote body cooling, but to minimise the risk of cold injury to the peripheries. However, this may have a number of effects. Firstly, all the heat flux transducers were positioned under areas of lesser clothing insulation, so the observed mean weighted heat flux values for the whole body may be an over-estimate. Secondly, it is possible that this distribution of insulation, and the consequent alteration of the normal skin temperature gradient between the trunk and the periphery, may alter the response of the thermoregulatory controller, and allow body temperature to fall faster than would otherwise be the case. This phenomenon has been demonstrated in water (15-17), and is currently the subject of investigation in air. It may explain why core temperature is allowed to fall in condition 1 at the same rate as in the more extreme conditions, when there is clearly physiological capacity to oppose the heat loss, although it may be argued that the mean skin temperature was simply not low enough in this condition to trigger the necessary responses (18).

One further point that needs addressing before the cooling curves produced by the model could be regarded as useful survival curves is the question of what happens to metabolic rate beyond the validated 90 minute point. The body has a finite capacity to produce heat by increased metabolism, and the fatiguing of this mechanism is likely to define the limit of survival in the less rapidly fatal conditions. The model incorporates a simulation of this fatiguing of metabolic rate, but it at present remains unvalidated in these conditions.

It appears then that we are well placed to describe a large proportion of the individual variation in fall of core temperature in terms of body morphology, and that, with refinement of the representation of clothing and metabolic response, a model similar to the one used in this study would be able to provide plausible boundary survival times for a variety of conditions, and hence recommendations on required cold-weather flying clothing. Further study is required on the effects of longer durations of exposure to less severe conditions, on the degree of intra-subject consistency of response, and on the effects of clothing distribution. In particular, the responses of thinner individuals who represent the more critical end of the population, and who were perhaps under-represented in this study merit further investigation. It is likely that for all but the most benign environments, the amount of clothing required to retain passive thermal equilibrium in the survival setting would be unacceptable in the cockpit, in terms of bulk and thermal stress, and this issue too requires addressing. It is fortunate that in most cases, the aviator's chances of survival would be enhanced by the provision of extra clothing and survival aids in some form of personal survival pack, and that he would be able to utilise the knowledge and experience gained during his survival training. Future improvements in the techniques of vacuum packing of clothing and sleeping bags in survival packs will perhaps circumvent the need for "dress to survive" policies for over-land flying, and allow aircrew equipment assemblies to be optimised for their primary task of operation within the aircraft.

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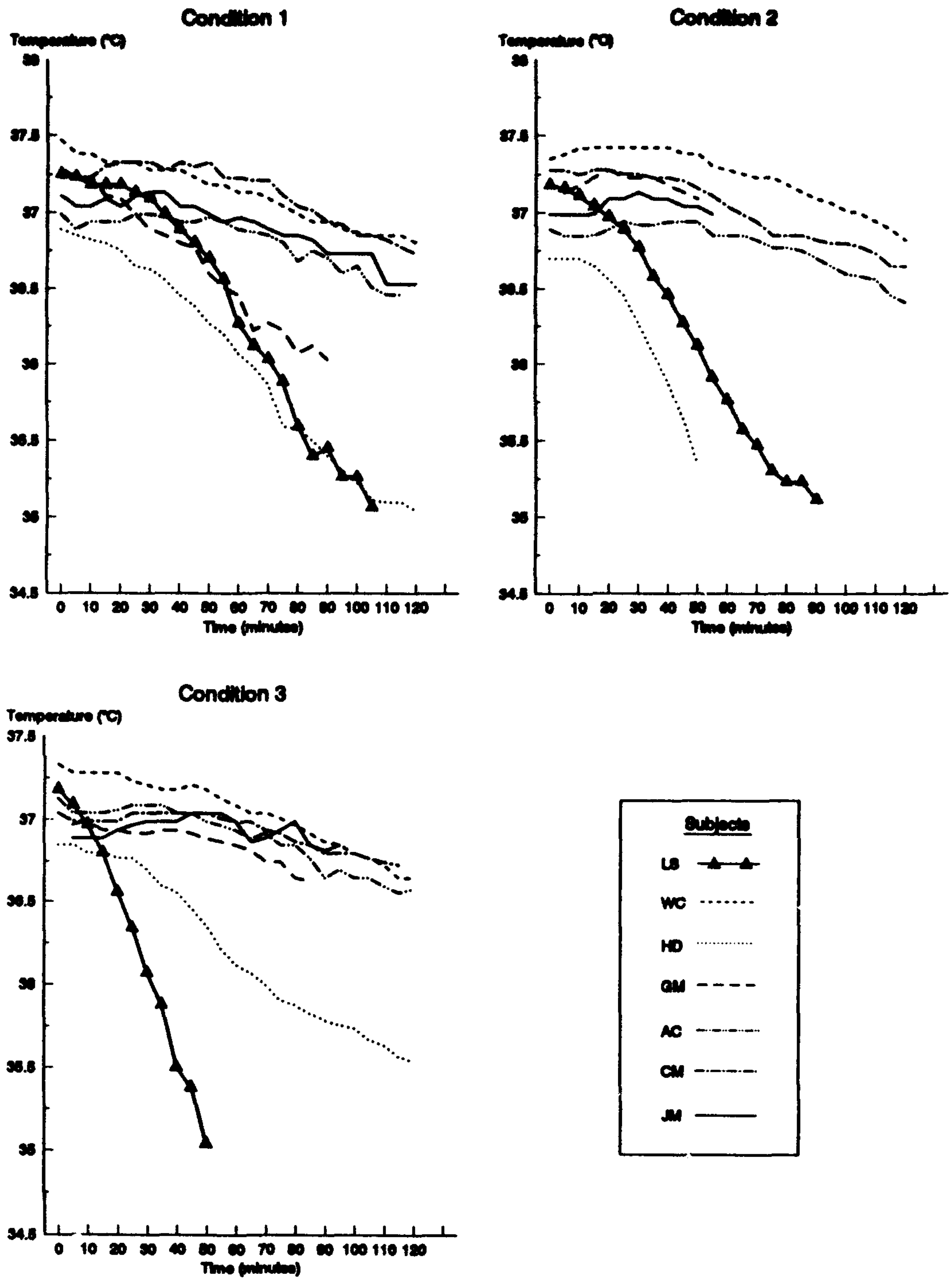

FIGURE 1 OBSERVED RECTAL TEMPERATURES FOR ALL SUBJECTS

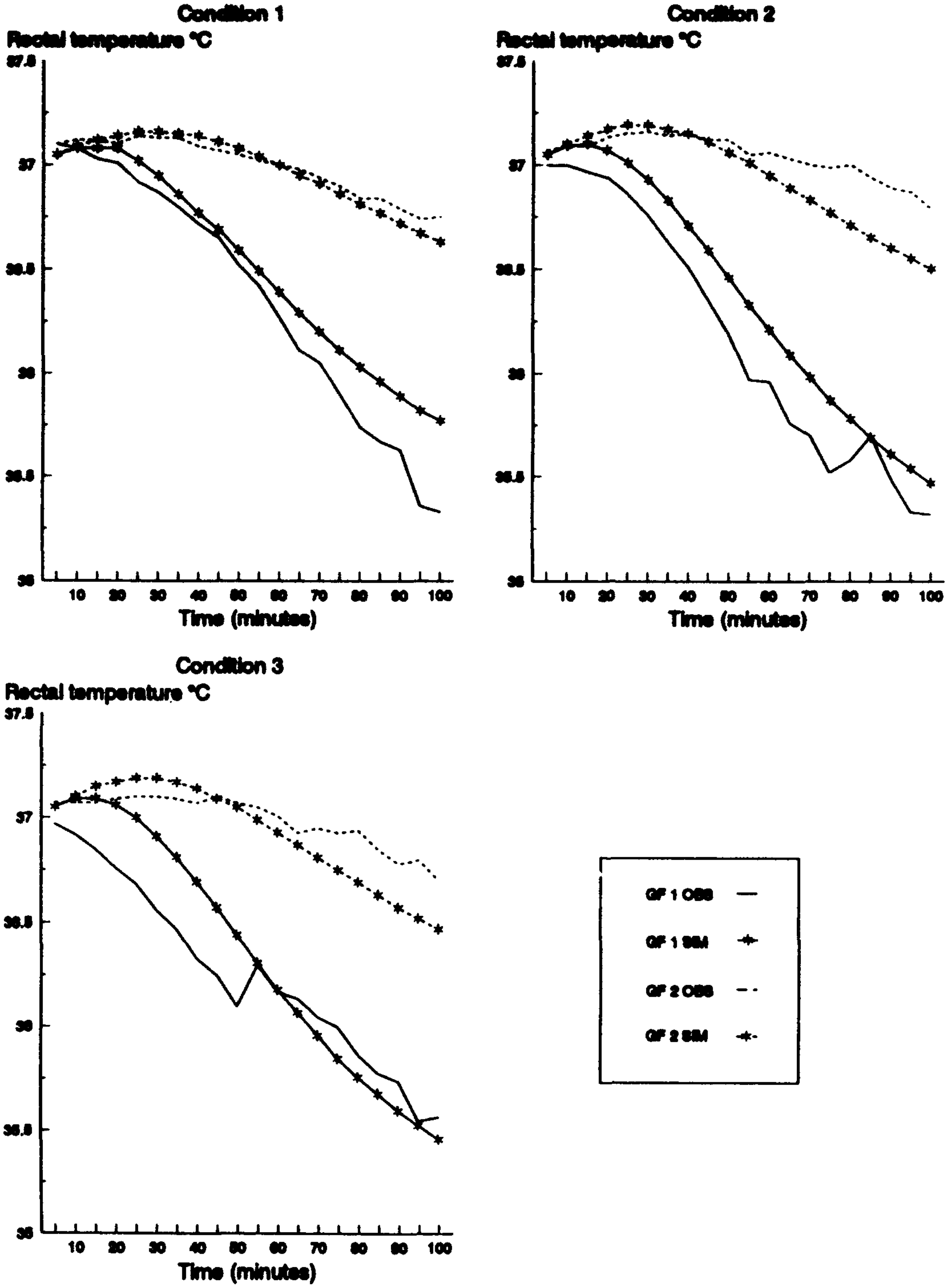

FIGURE 2 OBSERVED AND SIMULATED MEAN RECTAL TEMPERATURE

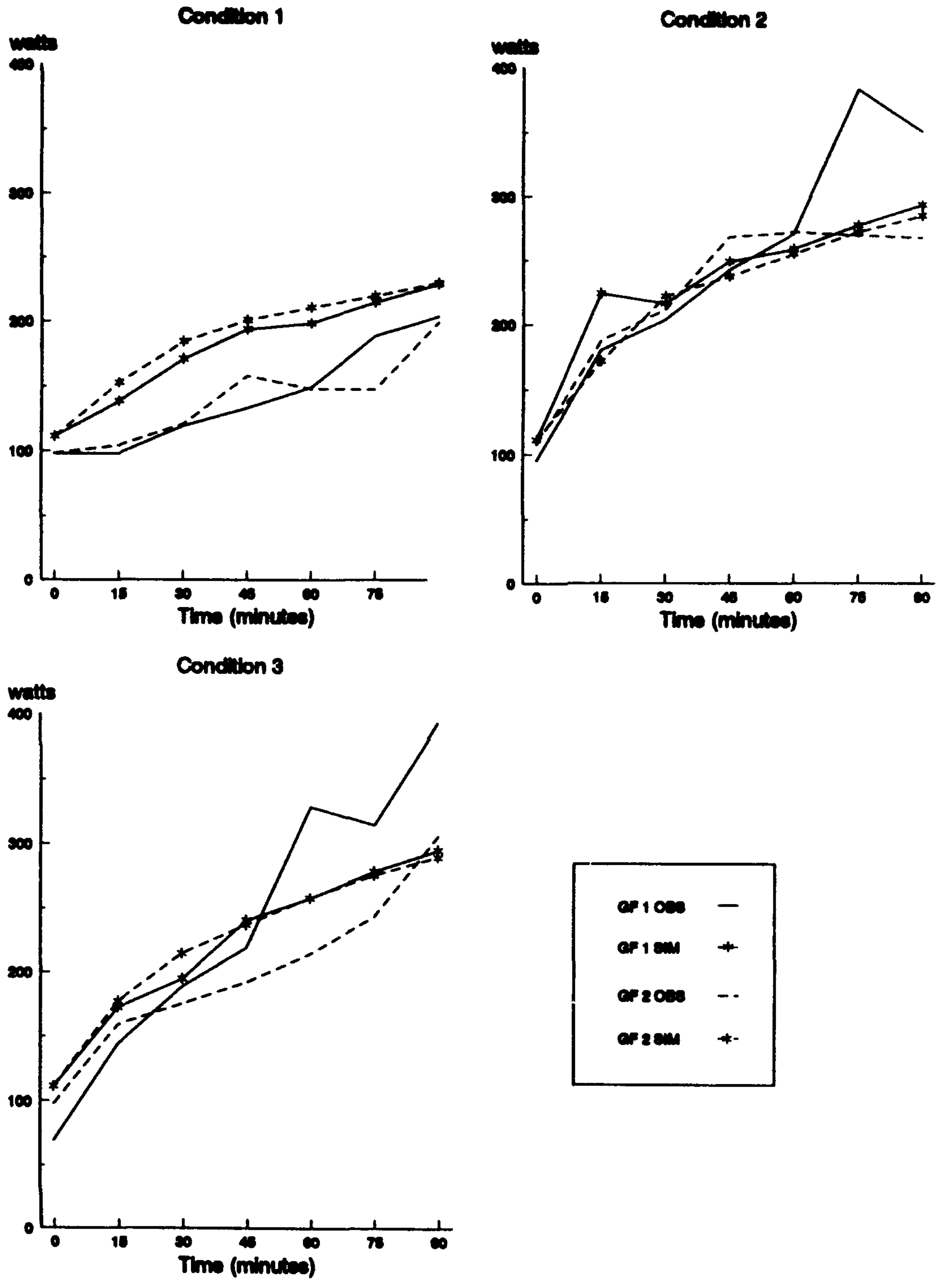

FIGURE 3 OBSERVED AND SIMULATED MEAN METABOLIC RATE

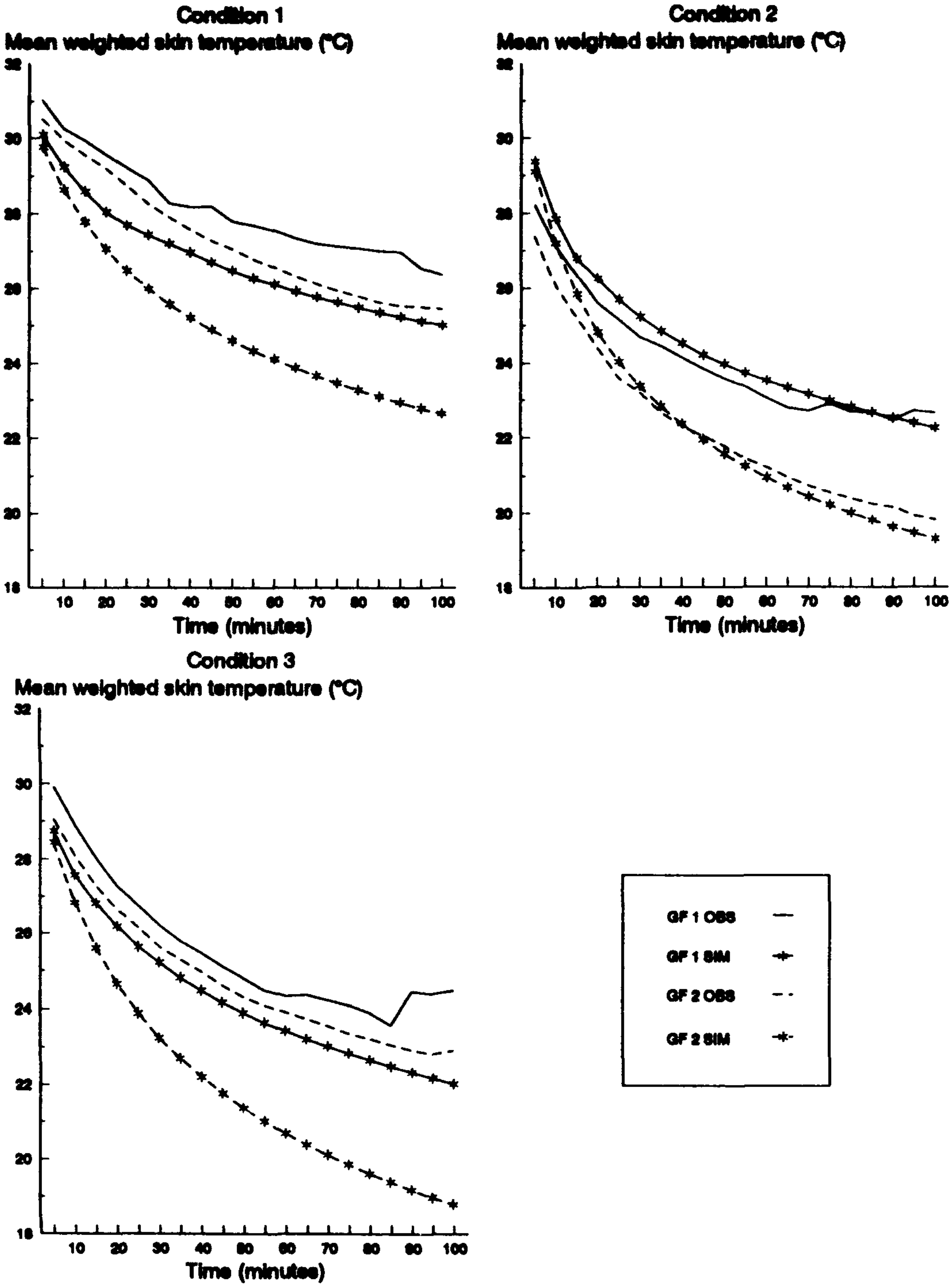

FIGURE 4 OBSERVED AND SIMULATED MEAN SKIN TEMPERATURE

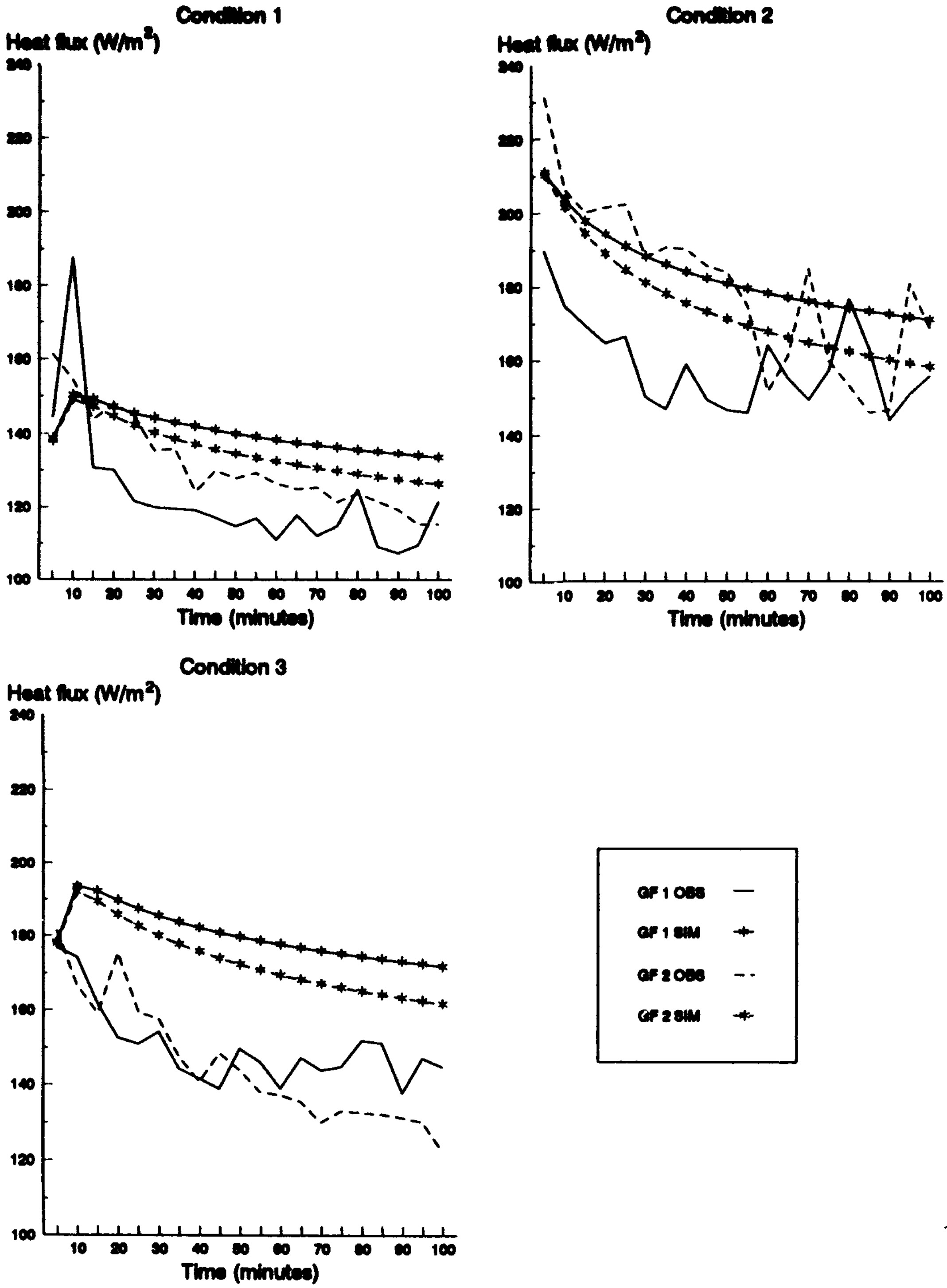

FIGURE 5 OBSERVED AND SIMULATED MEAN CLOTHING HEAT FLUX

THE CONCEPT OF ROYAL NAVY AIR OPERATIONS UNDER EXTREME ENVIRONMENTAL CONDITIONS

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Summary.

The Fleet Air Arm of the Royal Navy has always operated on a worldwide basis, with environmental extremes and therefore the accompanying stressors. Its procedures and essential support, including equipment and aviation medicine, have evolved to ensure a safe and efficient modus operandi. The post cold war concept of operations has proved the original philosophy. Recent events are discussed together with the aviation medicine implications.

Background.

General. The "Fleet Air Arm" of the Royal Navy has traditionally operated both in the embarked and disembarked roles. The former include fixed wing (Sea Harrier) with its air superiority and anti-surface roles: rotary wing, with Lynx providing the anti-surface (ASuW) and anti-submarine (ASW) capability from small ships; and Sea King: autonomous ASW, airborne early warning, and its HC4 variant, as an amphibious warfare support helicopter(SH). Thus although any unit may be called upon to operate from "ashore", primarily this task is undertaken by the HC4 Seaking, augmented as necessary by role modified MK 5 and 6 ASW variants.

Cold extremes.

Embarked. It is easily forgotten that a significant part of the NATO area includes seas with even summer temperatures of less than ten degrees Celcius. Thus there is always the conflicting requirement of aircrew (and support personnel) to dress to survive in a ditching environment where absence of appropriate survival equipment and clothing would hasten incapacitation and death from hypothermia and drowning (1), and yet comfortably for their normal working environment to avoid fatigue and heat stress. Realisation of specific hazards, such as the cold water gasp reflex (2), and remedial actions to include short term underwater breathing devices (3), and constant design improvements in immersion clothing to ensure good ventile properties combined with appropriate insulative properties (4,5) are essential if operational performance is not to be compromised.

Disembarked.

As part of its NATO role of supporting the Commando Brigade in the Northern Flank, the SHs must operate initially afloat, and then ashore in Norway. Here the temperatures may range from above zero to minus 40, with all the attendant cold wet and cold dry problems. Equipment scales reflect both

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needs. Rations with increased calories are needed to cater for the physical effort required to work and maintain body heat. Cold weather survival techniques are taught and practised, as a forced landing or forward operating situation may demand it. Biological and chemical warfare (BCW) necessitates the use of cold weather specific modifications to the standard assemblies to avoid cold injuries (6).

What has been the aviation medicine involvement? In terms of equipment the RAF Institute of Aviation Medicine has been intimately involved in the equipment programme, including proving trials, which are being reported separately at this meeting. The Institute of Naval Medicine provides a specialist officer to teach and oversee the cold injury aspects. Those who may be at risk in this environment, and those who suffer non freezing and freezing cold injuries are investigated at this Institute (7). Work is also being undertaken to determine the patho-physiology of the injury mechanism by blood flow measurement techniques and is to be reported shortly (8).

Hot climates.

Though subjected to the same direct thermal inputs, unlike fast jet or transport aircrew, helicopter crews do not have the luxury of proper cockpit or cabin conditioning. Temperatures in excess of 40 degrees C have been recorded, as have individual weight losses due to sweating which are known to cause performance impairment and heat stress even in the acclimatised. This "green house" effect of helicopters is as limiting in operational performance terms as the helicopter performance itself.

Efforts to reduce this have concentrated on the maintenance of as much heat loss through convection as possible. This has meant minimising the insulating effect of survival equipment assemblies as back packs and placing them in crashworthy seat pan (9), and educating aircrew to maintain body fluid levels by preloading and replacement.

The post cold war era.

Cold.

The comments pertaining to cold water survival are still pertinent. What appears less so are NATO Northern Flank SH considerations. However current operations as in aeromedical evacuation support to the UN in former Yugoslavia endorse the principles involved. Furthermore what must be appreciated is that it is an ideal training ground to test the skills and aptitude of both students and fully qualified personnel, and operating procedures, in a harsh and extremely demanding environment.

Hot.

The events of the last three years have amply demonstrated the problems in operating in an extremely hostile hot environment. These will be briefly described.

Operation GRANBY (Desert Storm).

The RN involvement was threefold.

Lynx ASuW operations from small ships (DD/FF) in the Northern Gulf.

Units operated in the forward zone for considerable periods, and achieved high, and via the media very public, success against Iraqi shipping with the Sea Skua missile. However in achieving the distinction of being the primary response, long hours at either high readiness alert states or actual flights posed an extremely demanding regimen on the crews. The climate, with temperatures of 40°C and one hundred per cent humidity, was stressful on its own, but the BCW threat necessitated the use of NBC protective equipment. The added thermal load required a high index of suspicion from the tasking authorities to avoid obvious flight safety considerations. Other equipment implications became apparent. The aircrew equipment assemblies life was shortened through the constant wetting by sweat : hygiene aspects assumed high priority, and even colour fast dyes in the helmet lining ran giving "rambo" like appearances!

SeaKing HC4 SH operations afloat.

The Royal Fleet Auxiliary RFA ARGUS was deployed in the Primary Casualty Reception Ship role in the Gulf in anticipation of the need to airlift casualties to offshore. In the event little was needed, but the crews faced the same challenges, although flights to the relatively benign thermal environment ashore were possible.

SeaKing HC4 operations ashore.

The primary role here was forward aeromedical evacuation of troops. As is known, the casualty numbers were light and therefore tasking was not as heavy as expected. Nonetheless the problem of operation in the desert, with sand recirculation, use of night vision goggles, and under the BCW threat all posed some additional loads. Paradoxically, rain was a greater nuisance than heat! No undue problems were encountered during the combat phase, but the casevac requirement continued into the early summer with temperatures into the 40's. The SeaKing has a typical helicopter problem, with overhead glazing in the cockpit providing direct solar heating, and attempts to provide some flow of air in the aircraft by opening the cabin door and cockpit windows only produces recirculation of exhaust fumes from the back forwards. The aircrew did not wear life preservers to minimise insulation whilst flying over land.

Operation Safe Haven.

The humanitarian crisis in "Kurdistan" followed hard on the heels of GRANBY, again requiring the use of support helicopters. The implications were subtly different. Temperatures were variable depending on altitude, but the greatest threat to flight safety was the field conditions and potential for poor hygiene. Scrupulous attention to food and sanitation hygiene was required. Outbreaks of gastro-intestinal disturbances occurred despite all this, with the accompanying fatigue and debilitation. Occupational hygiene expert opinion was that the causative agent was wind driven dust contaminated by sheep droppings, as laboratory testing failed to produce anything of substance. Whether true or not acclimatisation soon reduced the problem to an acceptable level.

A method of reducing heat stress at source is an important requirement from a

preventative viewpoint. For HAVEN liquid conditioning vests were considered. These posed some support difficulties in the field, requiring ice as the support pack heat exchange agent. Thus the obvious physiological and operational benefits are presently being negated until a proper support system can be incorporated which is compatible with SH operations. The principle of such a system is not new, as trials in the 1970s were performed using a portable heat exchange system in the UK (10,11). Further trials are anticipated and will be reported separately (12).

Conclusion.

An overview of Royal Naval Air Operations in environmentally hostile areas has chronicled recent events, noted aspects where the conditions have either potentially or actually impacted on operations, and remedial actions have been outlined.

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EFFECT OF SEASICKNESS ON AIRCREW STUDENT SURVIVOR ABILITY AFTER DITCHING IN COLD WATER

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1. SUMMARY

This presentation suggests that immediate, effective biochemical seasickness treatment for ditched aircrew does not exist, in addition to the fact that the severity of the problem in cold water survival is not currently documented, and therefore not sufficiently recognized.

2. INTRODUCTION

Aircrew faced with survival in extreme cold water can generally be divided into three classes: the high self controllers, the barely living, and those about to die from seasickness.

I always believed it was not possible to die from seasickness but over the years during training exercises at sea, I have observed how seasickness can very quickly cause a survivor to behave in such a way that, if left alone, would probably die. If later found at sea by Search and Rescue, the cause of death would likely be reported as drowning or exposure.

In an extensive literature search undertaken by Dr Jack Landolt et al, only four articles were discovered that commented on the effect of seasickness on the ability of personnel to perform in a survival situation on the sea. Landolt concluded in his work that only two studies in the literature actually focussed on the effects of seasickness in the survival of castaways. Both of these studies suggested "that seasickness could be a primary cause of death through choking on inhaled vomit and drowning or through general loss of will to survive, resulting in secondary drowning or hypothermia"(4).

Through the eleven years of training delivery at Survival Systems, staff members have witnessed various degrees of disability brought on by seasickness in program participants at sea. Their subjective view is consistent with Dr Landolt's conclusion that seasickness may contribute to loss of life in a much higher proportion of castaways than is currently being considered.

3. SEASICKNESS & SURVIVABILITY

My first experiences with seasickness were as a Sea King aircrew during three nauseous years on navy destroyers! Never having been airsick during my first years of flying I discovered that within five minutes of being on a rolling and pitching destroyer, I would get violently seasick even before I would get out of my poopy suit.

The only treatment and attention I received was to be told that it was all in my head and not to complain so much! So I endured and later left the military when I was threatened to be posted back to sea by my career manager.

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

My next experience with seasickness was in 1982 when I started to teach at Survival Systems as a sea survival and aircraft ditching training instructor.

As I had been instructed during my own sea survival training, and from extensive reading on the subject, I started by teaching our own students that seasickness was an enemy of survival but that cold water and indeed exposure were by far the real killers in a sea survival situation.

As a company, during the last eleven years Survival Systems has trained at sea off Nova Scotia on a year round basis approximately 4,000 aircrew, oil rig and marine crews. I have worked as an instructor for those sea survival courses for approximately seven out of the last eleven years. During those years I have concluded that exposure, drowning and hypothermia are probably not the principal causes of death in cold water survival situations.

I believe that often in shipping disasters, in World War II or incidents such as the Lakonia accident in 1963 in which 113 people died as a result of hypothermia, we do not correctly or clinically diagnose the true cause of death. Almost all of the dead had vomitus around their mouth, nose and ears. What part did seasickness play in these disasters?

In the TEMPSC Seasickness Survey Landolt et al "postulated that seasickness contributes to the loss of life in a much higher proportion of castaways than is currently being considered"(4).

During our extreme cold water survival training sessions, we will sometimes have 30 - 40% of the students become totally incapacitated from seasickness. By totally incapacitated, I mean that without our rescue swimmers or indeed assistance from other students on the course, those students suffering from seasickness would perish.

My first experience with such a student was a very traumatic one, which I still remember vividly today. Up to this point in my life I believed that all humans possessed an instinct to survive and would fight to live!

In this case, within five to nine minutes into our ship abandonment exercise our student decided to give up. I was trying to help him swim to the liferaft, which was drifting away with the rest of the group. Other students came to the rescue. They told me we should evacuate him back to the mother ship because he was probably suffering from hypothermia. He was wearing a 1/4 inch thick dry survival suit! The skin on his face was warm. As the waves crashed over his face and body he would keep his mouth open, would not swim, would vomit on his own face and regurgitate helplessly.

I tried repeatedly to urge him to do something, to swim with me as now I had cramps in my legs trying to pull him to the liferaft without success. I told the others to go to the liferaft before it was too late for them and their own survival. I told our student, "Listen, if you don't do anything to help yourself and if this was for real you'd be left behind and would probably die."

With big tears in his eyes and straining to vomit he said, "Just leave me to die, I can't, I can't, I can't."

I asked him, "Do you refuse to try?" He wouldn't even reply with his mouth open as big waves

crashed over his face. I became furious. I remember thinking I should bite him to get him going. Then I thought to myself that he probably wouldn't even have the guts to bleed. Relax! I didn't. We then evacuated him and carried on our exercise with the others.

Twelve years later, we as instructors are still watching this, and have no better advice or cure to prepare potential survivors to face seasickness. I even believe that when we teach survivors to take seasickness tablets, we are indeed possibly setting them up to die.

When a survivor is attempting to survive in -20°C air temperature and -1°C water temperature (which we teach in for two to three months of the year) one does not need numb reflexes, poor balance, induced sleepiness and drowsiness as one tries to fight desperately to maintain the three essential body or survival balances.

In my opinion, other than making survivors groggy and unresponsive, I do not feel that those who take current oral seasickness medication perform so much better than the others who did not take medication, or that indeed get less seasick.

Landolt et al's TEMPSC Seasickness Survey reported that during the VINLAND Incident, 90% of the survivors were violently seasick even though they had been issued with anti-seasickness drugs.

In most helicopter ditching situations, it means aircrew face immediate entry into a survival situation and very often without a liferaft. This means there would be no available seasickness pills. Even if there were, the common seasickness pills would not have time to take effect before survivors became seasick.

Do we understand the process of seasickness and what it really does to survivors battling for their lives in sub-zero weather, high winds and sea states?

My last memorable experience with seasickness was last winter with a 19 year old student who I was at sea with. He was young and fit, a new entry into the offshore industry. During the course on the psychology of survival and the discussions on seasickness as an enemy or threat to survival, he finally raised his hand and said, "Come on, isn't all this a little too dramatic!"

Later, during the sea survival phase of the course, I watched him becoming seasick in a moderate swell. Shortly thereafter he threw up in his face and gave up on life, even refusing to talk or indicate that he was still alive and breathing.

During difficult sea survival training exercises, by routine we ask students to confirm their state of well-being every five minutes or so! I held him in my arms as I washed away the frozen vomit all around his survival suit, hood, face and neck seal. I threw up myself a few times (it's very catching!) and then, towards the end of the exercise, we hauled him out of the water using two rescue swimmers and even had to carry him across from the fast rescue craft to the mother ship. He could not even stand up.

Later, during the course wrap-up, he told me, "If you had told me that you could take me to death itself, which is how I felt, I would have laughed in your face. But you know, I was there, completely helpless, as good as dead."

During the recent "Cape Aspey" disaster off Nova Scotia, where one fatality was found with a survival suit face down in the sea, I received a call that morning from our Rescue Coordination Centre in Halifax. The officer asked me, "How could he die? He had a survival suit on." I replied that he had probably died from seasickness.

But then, do we really die from seasickness? I do not know. I am not a researcher, a scientist nor a medical doctor. I have only lived this near-death experience with countless students over the last many years. We have only discovered this by subjecting ourselves and our students through this harsh realistic training process. This indeed has been the most challenging and difficult form of survival training that we do. It is also one of the most confidence skill building experience for the students. One remark by a non-swimmer, scared-of-everything, student at the end of the survival course was, "Give it to me now, I think I can survive anything." It is important that survivors believe that these are their odds right from the beginning.

My theory is that nowadays human beings do not know what pain and suffering feels like, or indeed how disabling and shocking the experience can be. We need to factor this into our predicted survival times, the design of our equipment and the development of our procedures as they pertain to safety and survival equipment. We need to observe and study real seasickness in a non-standard, non-clinical way, perhaps outside of our ethical protocol to really understand its effects and be able to develop solutions.

In 1988, the oil rig "Rowan Gorilla I" capsized and sank while under tow from Halifax, Nova Scotia, Canada to Ireland. All 27 personnel on board escaped in an enclosed lifeboat and were rescued without loss of life 22 hours later. Of the 27 persons on board, 23 became seasick. Many noted the practical aspect of their training as a key component contributing to their ability to cope and conclude the incident without loss of life.

What about those who have not been trained or indeed experienced this? We also have good, calm, training days and very often aircrew fly many months or years before they receive sea survival training.

I flew for six years over cold water and at least half of that time in and around the East Coast of Canada with its harsh weather environment. Having only ever taken sea survival training in the summer months and not during the severe cold weather environment, I had no idea what I would have to face if I ever ditched in the winter months. I may not have survived for not having anticipated or being in a category of persons that Rosenbaum et al's Self Control Schedule would call "high self-controllers"(8).

For those who may not be familiar with this schedule, during seasickness Rosenbaum's high self-controllers used more extensive self-control methods, showed fewer performance deficits and less performance deterioration than the low self-controllers group.

The study of Gal (1974) indicated that the key to any individual's coping ability with seasickness and avoidance of deterioration in performance occurs only if the individual has high self-control stra'egies or approaches (1). If an air-

crew has no clue or the least idea of what is about to happen to him or her, my own experience suggests that the shock of being suddenly immersed in a ditching situation is overwhelming. Skin contact exposure to the extreme cold air and water gives a burning sensation which then rapidly incapacitates your hands. This immediate disability and the sudden onset of seasickness creates first a physiological disability for 30 to 40 % of survivors, which then becomes a psychological inability to cope and, finally, a complete abandonment of effort or will to survive.

I have now seen cases where individuals who are returning to sea survival refresher training and who become seasick are not only able to cope and demonstrate a good ability to carry out what I call survival behaviour, but often can and do actively take charge of group activities and assist others.

In extreme cold water survival it is only through very, very aggressive individual and group survival actions that everybody who in theory should survive, will survive. In survival training, we talk of thermal, caloric, fluid balance and the criticality of maintaining such. The body's need for water is second to its need for oxygen and breathing. A 10% loss of body water puts one at risk and a 20% loss is generally fatal. During a survival situation, the survivor will generally go through a short period of intense activity which can cause a loss of up to two litres in sweat. With the onset of seasickness and the subsequent loss of all the fluids and energy nutrients that may be in the stomach, plus the amount of physical effort required, this rapidly puts the body behind the energy production curve. With no extra energy available, and no additional fluids available to produce heat and energy or physical activity, the body rapidly becomes out of complete balance in all three critical aspects. This is when we see complete physical and psychological abandonment by survivors.

Many times during the last eleven years while trying to urge seasick survivors into survival actions of some sort, I have been asked by them to "leave me alone" and "let me die". Maybe this is how badly they wanted me to leave them alone, or perhaps it was a true reflection of their inability or psychological state of survival.

At present, Survival Systems has teamed up with a Dartmouth, Nova Scotia company to conduct an ongoing survey of the effects of seasickness on students participating in sea exercises. This study is being conducted by Paul Potter of The CORD Group Limited for the Canadian National Energy Board. The National Energy Board is responsible for regulating Canadian oil and gas exploration and development. The National Energy Board, through the Committee Panel on Energy Research and Development (PERD) supports many research and development projects like this.

This study will be ongoing over the next twelve months, with the final outcome of providing observations and statistical information on the effects of seasickness on a variety of survivors' ability to carry out sea survival actions during training in various sea states.

As a final exercise in their training, trainees participate in a half-day sea exercise. The exercise is conducted four miles off the coast of Halifax, Nova

Scotia and consists of distress flare firing from a 50 ft vessel, a simulated abandonment into the ocean and marine liferaft, a one hour period in the liferaft, a half-hour swim, a 15 minute exercise in the aviation liferaft, recovery to the rescue boat, transfer to the larger vessel and return trip to Halifax. Throughout these exercises an observer records information relevant to the seasickness study and a video record is kept for development into a final film review of the project. Weather and sea state conditions at the site are recorded.

Upon arrival back in Halifax, participants are requested to complete a questionnaire. A separate questionnaire is provided for the instructional staff. Interviews of seasick participants are conducted before completion of the course.

The final objective of the study is to provide statistical information relating to sea state, weather, activities related to seasickness, seasickness medication if any used, and general performance. Video observations will accompany the final report.

It is hoped that this study will help to contribute to the body of knowledge concerning the effects of seasickness on the performance of personnel in sea survival scenarios and ultimately to assist in the development of more useful means of assisting those persons in avoiding and overcoming the debilitating effects of seasickness.

4. CONCLUSION

I cannot resign myself to the fact that we, as survival trainers, may have to continue to make people sick to adequately prepare them to face survival situations as reported by the Rowan Gorilla I survivors.

I cannot accept that we cannot find a possible medical, biochemical solution; one that can be taken immediately during a survival situation, be readily effective, and most importantly non-disabling.

J'aimerais finir cette presentation en vous invitant a me joindre a cette poursuite pour etudier, trouver et, developer des solutions pratiques pour les cinetoses qui font face a des conditions de survie en mer froide.

Mes observations des consequences du mal de mer soit: la deshydratation, les pertes hydro-minerales, l'atteinte du psychisme, l'aggravation des etats pathologiques suggere qu'il faut, trouver, d'autres solutions que celles qui existe aujourd'hui.

To the ditched aircrew who become instant victims plunged into a new, unexpected, very threatening environment, we need to offer better solutions than we have done to date.

At present there is little concrete, useful or new information available for training organizations to give to potential survivors who would in all likelihood not have seasickness medication available, or if available the medication would probably not be effective once taken.

As newer technologies such as survival suits and specialized clothing significantly contribute to increased survivability for ditched aircrew in cold water, so must new, useable, more effective, biochemical treatments for seasickness be developed. The challenge is ours!

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FUELLING SHIVERING IN HUMANS DURING COLD WATER IMMERSION

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SUMMARY

Military cold survival research has traditionally concentrated on ways of conserving body heat. In contrast, this paper will describe our recent investigations of metabolic heat production during cold exposure. In humans increased heat production in the cold is achieved by increased shivering, i.e. involuntary intermittent skeletal muscle contractions, which must be fuelled. Our research has focused on the thermoregulatory effects of manipulating the availability of specific fuel substrates to the shivering musculature. Using procedures such as muscle biopsies to quantify intramuscular substrate utilisation, venous blood sampling to quantify circulating substrates, and continuous monitoring of metabolic rates and rectal temperatures during cold exposure, we have demonstrated the importance of skeletal muscle carbohydrates stores for the ability to maintain heat production and delay the onset of hypothermia during cold water immersions. Acute reductions in muscle carbohydrate stores were associated with significant reductions in heat production by the body during shivering, and a more rapid decrease in rectal temperature. In contrast, another series of studies induced acute reductions in circulating fat stores, but there was no effect on body temperature regulation. The availability of sufficient carbohydrate stores to the shivering musculature seems to be critical for the body's ability to delay hypothermia during acute cold stress.

1 INTRODUCTION

By measuring the electrical activity of many muscle groups simultaneously during cold-induced shivering, we now know that several large muscle groups are recruited and contract at relatively low intensities that are less than 20% of their maximum force generating capabilities (1). Since so many muscle groups are involved in shivering, the sum total of their contractile activities can result in a four or five-fold increase in metabolic rate, and heat production. Much of our attention has been directed towards the substrates that are used by skeletal muscle to increase heat production during shivering. Until about a decade ago there was very little empirically based information available in this regard for human subjects. So we initiated some fundamental experiments in an attempt to fill this knowledge gap.

For example, Vallerand et al. (2) administered a clinical glucose tolerance test to subjects who were sitting in cold air for two hours and again while sitting at a comfortable temperature. These data were the first to show in humans that glucose is eliminated more rapidly from the circulation during cold exposure, presumably to provide more available substrate to fuel the increase in metabolic rate. It is also noteworthy that this more rapid uptake of glucose during cold exposure occurs with lower insulin levels in the cold compared to warm temperatures.

We have subsequently continued to attempt to quantify the rates of substrate oxidation of fat, carbohydrate and protein in humans during cold exposure with indirect calorimetric techniques. As one might presume, the increase in metabolic rate during shivering is caused by increases in oxidation of both fat and carbohydrate, but the relative increase in the rate of substrate oxidation caused by shivering is greatest for carbohydrates (3). In resting subjects exposed to either cold air or cold water carbohydrates and fat contribute approximately equally to heat production (3,4). From a strategic point of view, this finding seems unfortunate because the body's availability of carbohydrates is quite limited compared to the abundant fat and protein stores.

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We were already aware of the well established positive relationship between muscle glycogen concentration and endurance exercise performance of skeletal muscle. We therefore speculated that there may be a similar detrimental effect caused by an unavailability of muscle glycogen on another form of muscle contraction, i.e. shivering and the associated heat production.

2 CARBOHYDRATE AVAILABILITY AND COLD TOLERANCE

In our studies we used the needle biopsy technique to withdraw, under local anaesthetic, a small piece of muscle tissue. This technique is very innocuous and enables biochemical quantification of metabolic events within the muscle cell. We used cold water immersion at 18°C for our experiments because it is a way to very rapidly overwhelm the body's ability to compensate for heat loss by increasing metabolism. The subjects were removed from the water when their rectal temperature reached 35.5° C. Biopsies were taken from the thigh muscle before and after the immersion to evaluate the changes in glycogen as a result of the water immersion (5). We also carried out a series of studies in which the muscle glycogen concentrations were manipulated prior to water immersion by appropriate dietary and exercise protocols (6); the purpose of these studies was to evaluate the effects of very low and very high glycogen levels on metabolic heat production during the water immersion.

Metabolic rate during cold water immersion, expressed as oxygen consumption, increases to values that are usually around 4 or 5 times normal resting metabolic rate. Infrequently we have observed individuals who exhibit somewhat higher values, 6– or 7 times resting values. Our initial studies suggested that part of this increase in metabolic rate is fuelled by muscle glycogen, as all of the subjects demonstrated a decrease in leg glycogen concentration after the water immersion (5). The second objective of these experiments was to evaluate the effects of manipulating the pre-immersion glycogen levels on heat production during cold water immersion. Our manipulations did result in the subjects entering the water on one trial with muscle glycogen levels that were only about 50% of normal, and on another trial when they were about 150% of normal (6). The oxygen consumption during the water immersion, was about the same on each trial. The respiratory exchange ratio (RER), which is the ratio of carbon dioxide produced divided by the oxygen consumption, differed between trials as expected. An increase in the RER is interpreted as reflecting an increase in the proportion of energy that is transduced from the oxidation of carbohydrates; a decrease in the RER reflects an increase in the proportion of energy transduced from fat oxidation. Metabolic heat production is calculated based on the combination of RER and oxygen consumption. We observed significantly less metabolic heat production per unit time when the body's carbohydrate stores were depleted compared to the other trials (6). There was also a significantly more rapid body cooling rate, as reflected by the changes in rectal temperature, when the body had little glycogen stored in its muscles, and presumably also in the liver (6). If we were to take these observations on body temperature cooling rate and try to translate the effects into how long a downed pilot, for example, would last in cold water before becoming severely hypothermic, our results suggest that in the glycogen depleted state, the individual would cool to a potentially critical temperature significantly more rapidly. Based on the efficiency with which search and rescue activities are coordinated today with the aid of the SARSAT, this time interval is indeed significant.

These examples of some of our initial studies were done on subjects resting in cold air or cold water. In light of our findings we hypothesized that the requirement to do physical work superimposed on that cold stress might induce a more rapid breakdown of muscle glycogen than if the same work were done at a comfortable temperature. We therefore had subjects performing either light or heavy exercise once at 9°C air and again on a separate day at 21°C (7). We intentionally recruited lean subjects, so that they would begin shivering quickly during their cold air exposure. We found that significantly more glycogen was in fact utilized to do the light exercise in the cold compared to doing the same work at 21°C. There was no difference in glycogen depletion rates, however, for the higher exercise intensities, and this is consistent with earlier observations that the heat production associated with hard exercise is sufficient to offset heat loss to the environment, thus obviating the need for shivering.

3 FAT UTILIZATION AND SHIVERING

We also carried out investigations of the effects

of manipulating the body's circulating fat pools on heat production during cold water immersion. Vallerand and Jacobs (8) reported that triglycerides infused into a vein were not eliminated more rapidly from the circulation during cold air exposure than during warm air exposure, contrasting with the results for glucose infusion (2). In another series of experiments, the circulating free fatty acid concentration was manipulated by having our subjects ingest nicotinic acid in the form of niacin pills prior to and during the water immersion (4). The effect of the nicotinic acid is to block lipolysis and this effect is demonstrated by the observation that the plasma free fatty acids and glycerol levels were dramatically reduced prior to, and during, the water immersion. Again contrasting with the effects of manipulating the carbohydrate stores, metabolic heat production was virtually unaffected; the proportion of the total heat production that could be attributed to fat oxidation was significantly reduced, but there was compensation by simply increasing carbohydrate oxidation.

4 THE PREFERRED FUEL

For reasons that are still unclear, carbohydrates seem to be a somewhat preferred substrate during shivering thermogenesis. There are similarities to hard physical exertion in that the body is not able to maintain the same intensity of exertion when carbohydrate stores are depleted, i.e. a shift to a greater reliance on fat oxidation to fuel muscle contraction is not sufficient for the musculature to be able to maintain a high level of exertion, just as body temperature was not able to be maintained as well when carbohydrate stores were depleted (6). We must mention that similar experiments were carried out at USARIEM and they did not detect any significant muscle glycogen utilization during cold water immersion (9); we can not explain the discrepancies between our studies other then to suggest that perhaps the fact that our subjects were much leaner than those of Young et al. (9) may be important in this regard.

5 APPLICATIONS

The above brief summary of some of our recent work describes fundamental research which was required to understand how skeletal muscle fuels shivering. Only after such an understanding is achieved can we then consider the development of a substance or procedure that could be applied in an acute survival situation, i.e. to enhance thermogenesis during shivering and by doing so, delay the time to onset of life-threatening hypothermia. Such applications have in fact been developed and are described in the accompanying article by A. Vallerand.

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BIOCHEMICAL ENHANCEMENT OF COLD TOLERANCE

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SUMMARY

It is well established that humans have a poor resistance to cold. Once the insulation provided by the microclimate and by peripheral vasoconstriction has been maximized, the last line of defence against the cold resides in an increase in metabolic heat production ($\dot{M}$). Several techniques have been used to further enhance $\dot{M}$ in the cold, but it is a pharmacological approach that has received the most support. To that effect, recent experiments in cold-exposed subjects have shown that the ingestion of ephedrine (E; a decongestant) and caffeine (C; a methylxanthine) improves $\dot{M}$, heat debt (body heat deficit) and the drop in body core (rectal) temperature (T_{re}) ($P<0.05$). The ingestion of an E, C and theophylline (T; a bronchodilator) capsule produced about the same beneficial effect ($P<0.05$). Although some authors have reported that T alone reduces the drop in T_{re} (i.e. warmer T_{re}), these improvements require further clarification since $\dot{M}$ and mean skin temperature ($\bar{T}_{sk}$) practically did not change. A theobromine-based (another xanthine) Recreation and Sports bar (Cold Buster™) is purported to reduce the drop in T_{re} and thus delay the onset of hypothermia. However, such claims could not be confirmed in two different studies performed in our lab. Despite an increase in $\dot{M}$ in some studies, C alone did not alter T_{re} in the cold. It is concluded that ephedrine/xanthine mixtures represent at the moment, one of the best and safe pharmacological agents to enhance heat production and cold resistance.

1 INTRODUCTION

Due to our high capacity for heat loss and poor resistance to cold, humans are considered tropical animals (1). It is therefore not surprising that numerous experiments have attempted to enhance man's tolerance to cold. Various diets, different exercise regimens, repeated exposures to cold air or cold water as well as the administration of various hormones and pharmacological agents have all been used (2, 3). The use of a pharmacological approach with thermogenic agents is certainly an attractive and promising approach. Knowing their importance, relevant animal studies will first be briefly reviewed, before focusing on human studies.

2 ANIMAL STUDIES

While studying endocrine responses to the cold, it was found that the administration of several hormones (for various periods of time) could markedly delay the onset of hypothermia. Such hormones include catecholamines, thyroxine, the combination of thyroxine and cortisol, and growth hormone (for a review see 1, 4). Although there is no doubt that these studies were very useful in our understanding of cold-induced thermogenesis, it is apparent that they have little direct application to humans. For instance, the catecholamine-induced improvement in heat production is directly related to brown fat, the long-term use of high doses of thyroxine is not recommended in euthyroid subjects, the long-term use of high cortisol doses increases protein breakdown and is associated with Cushing's syndrome, the long-term use of growth hormone leads to insulin resistance and is associated with acromegaly. In parallel, a wide variety of pharmacological agents have been shown as effective in delaying the onset of hypothermia in animals.

Dinitrophenol has been shown an extremely potent thermogenic agent since it uncouples oxidative phosphorylation (5). However, this uncoupling effect is generalized to virtually all tissues. The thermogenic effect of dinitrophenol

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is even magnified in the presence of thyroxine (6), but again it is difficult to find an application to humans. Other effective compounds in the cold include vitamin C, alpha amino acids, strophantin, chlorpromazine, coramine, cardiozol, etc. (see 3). Of much greater interest today, are methylxanthines.

Caffeine (C), the most well-known methylxanthine, is an established thermogenic agent at comfortable ambient temperatures (7, 8). In the cold, it has been shown to significantly reduce the drop in T_{re} in animals (9, 10). Another effective xanthine is theophylline (T). During the last decade, Dr. Wang has repeatedly shown the significantly warmer T_{re} associated with the thermogenic effect of an acute administration of T in rats (11-13). Other potent agents in the cold include amphetamines, CNS stimulants (14) which, with or without epinephrine (15), have been shown to markedly increase $\dot{M}$ and to produce significantly warmer T_{re} in the cold. It appears as though sympathomimetics and methylxanthines are two classes of pharmacological agents which are likely to be useful in cold-exposed humans.

3 HUMAN STUDIES

As early as 1942, Scheurer reported that the ingestion of C in men exposed to a cool ambient temperature reduced the drop in mean skin temperature ($\bar{T}_{sk}$) and thus ensured a warmer $\bar{T}_{sk}$ (16). Similarly, LeBlanc (8) found that C ingestion before retiring for the night in a cool environment, significantly increased oxygen consumption and provided a warmer $\bar{T}_{sk}$, with no change in T_{re}. Other studies which have analyzed the effect of C in the cold have confirmed that it has little influence on T_{re}. They have also reported that it tends to exaggerate the drop in $\bar{T}_{sk}$ in cold air (17, 18) or that it offers no benefit in cold water, in spite of an important increase in $\dot{M}$ (19).

Following up on his animal work, Wang et al. showed that the drop in T_{re} in cold-exposed individuals can be greatly reduced with the prior ingestion of T. This was demonstrated in acute cold air studies performed either at rest or during intermittent exercise (20-22). It was suggested that, like in animals, the effectiveness of T in enhancing cold tolerance, as defined by the drop in T_{re}, resided in an

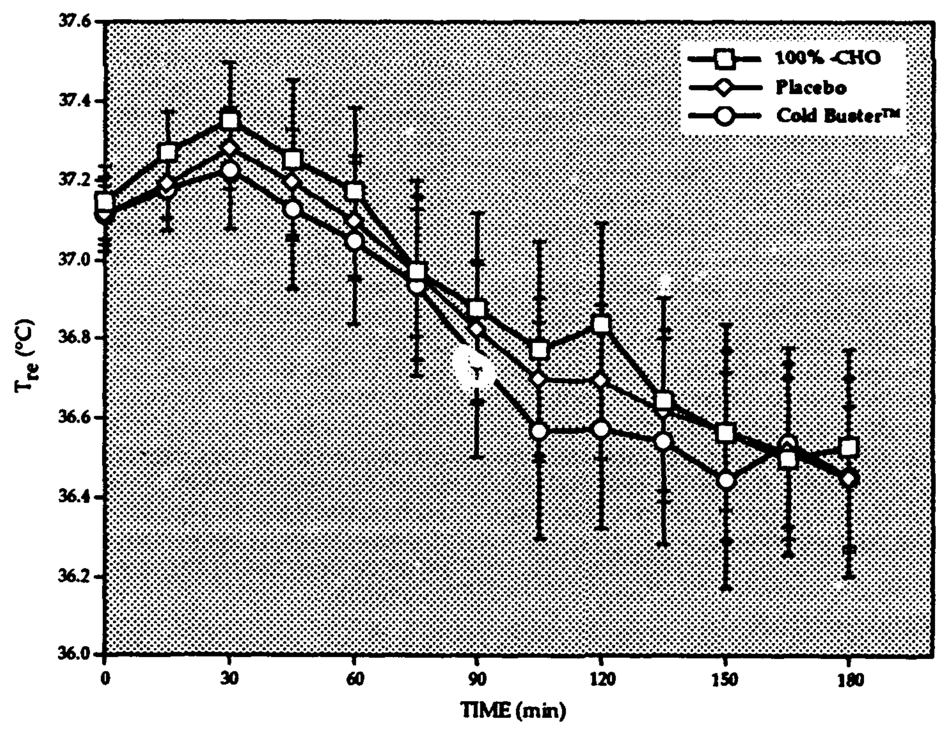

Fig. 1. Influence of pure carbohydrate (100%-CHO) or Cold Buster™ sports bar on T_{re} profile during 3h exposure at rest to 5°C, 1m.s^{-1} wind. Results are mean ± SEM.

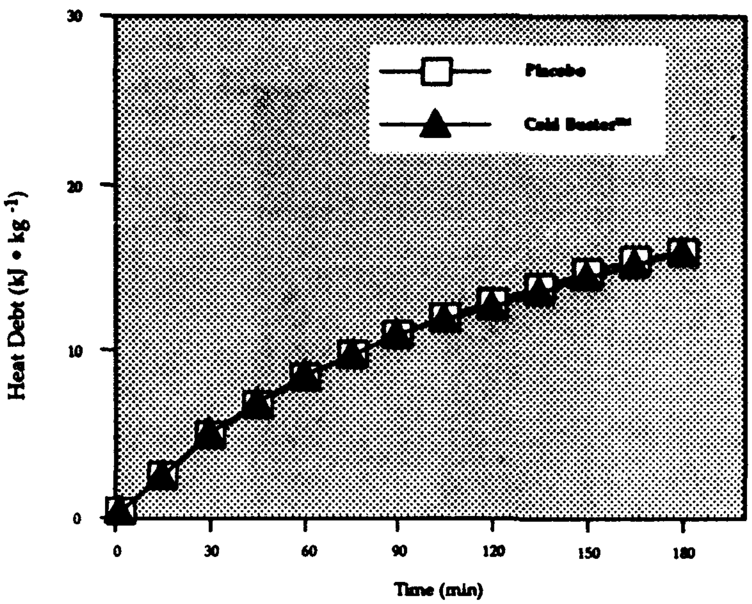

Fig. 2. Heat debt (balance of heat production minus all heat losses) during 3h exposure at 10°C, <0.4 $m.s^{-1}$ wind, following the ingestion of a placebo or the Cold Buster™.

enhancement of energy substrate mobilization, a limiting factor for cold-induced thermogenesis and thus cold tolerance (11, 12, 20, 23). Although this theory seems well suited for animals, the corresponding metabolic data in humans is surprisingly not convincing, since the marked improvements in T_{re} described in humans above, were not accompanied with any significant changes in $\dot{M}$ (20-22). Since it is important to the understanding of the biochemical enhancement of cold tolerance, it was decided to re-investigate this concept linking energy substrate mobilization, cold thermogenesis and cold tolerance.

4 CAN SUBSTRATE MOBILIZATION ALTER COLD THERMOGENESIS?

Based on the above theory, a commercially available "Recreation and Sports bar" (Cold Buster™) has been recently developed. It is purported to markedly delay the onset of hypothermia in humans as a result of its substrates and theobromine (another xanthine) content, which affect substrate mobilization. After proper familiarization to ensure a high reproducibility between cold tests (< 5% of variability; 24), fasting semi-nude (jogging shorts only) subjects were exposed (single-blind protocol) on three occasions (1 wk apart) to the cold following the ingestion of either a placebo, pure carbohydrates (CHO) or the above-mentioned sports bar in isocaloric amounts (340 kcal or 1422 kJ). Results showed that there were no differences across all three trials with respect to T_{re}, $\bar{T}_{sk}$, M and the heat debt (minute-by-minute mathematical balance of heat production minus all heat losses) (Fig. 1; 25). Further, ingesting either the pure CHO (Canadian Forces Survival Rations) or the sports bar did increase CHO oxidation, as expected, but entirely at the expense of lipid oxidation in both cases, with no change in M (25). Surprised by the conflicting results, we immediately proceeded to re-test this theory (and the sports bar) in another study performed in different conditions with different subjects. Identical results were obtained (Fig. 2; 26).

Can differences in experimental protocol explain the fact that we could not confirm Wang's energy substrate mobilization theory? One possible explanation is that our subjects were at rest in the cold. With shivering alone, M rose to about 2.5 to 3.5 times over resting M (25, 26). Wang et al. have suggested in some studies (21, 22) but not all (20) that a higher M, such as that seen during intermittent exercise, is required to fully exploit the energy-mobilizing effect of ingesting substrates and/or xanthines on cold thermogenesis and cold tolerance. Unfortunately, when

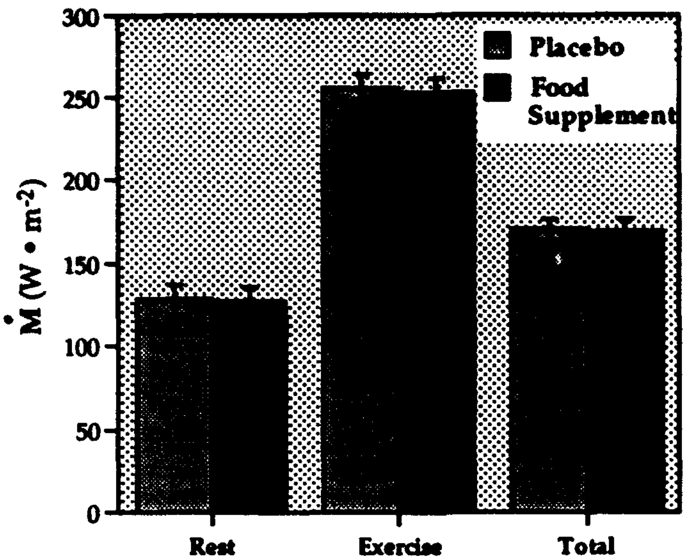

Fig. 3. Metabolic rate in the cold following the ingestion of placebo or food supplement during intermittent exercise.

M was raised by about 3.4 times and by as much as 6.7 times over resting values during the intermittent rest/exercise protocol, similar to Wang et al. (21, 22), the ingestion of a food supplement containing substrates and theobromine had no influence on M, T_{re}, $\bar{T}_{sk}$ and heat debt (Fig. 3; 27). Exactly as before, the high-CHO food supplement also increased CHO oxidation at the expense of lipid oxidation (27).

Another possibility is that the dose of substrates was not optimal to observe a positive influence of substrate mobilization on M. This

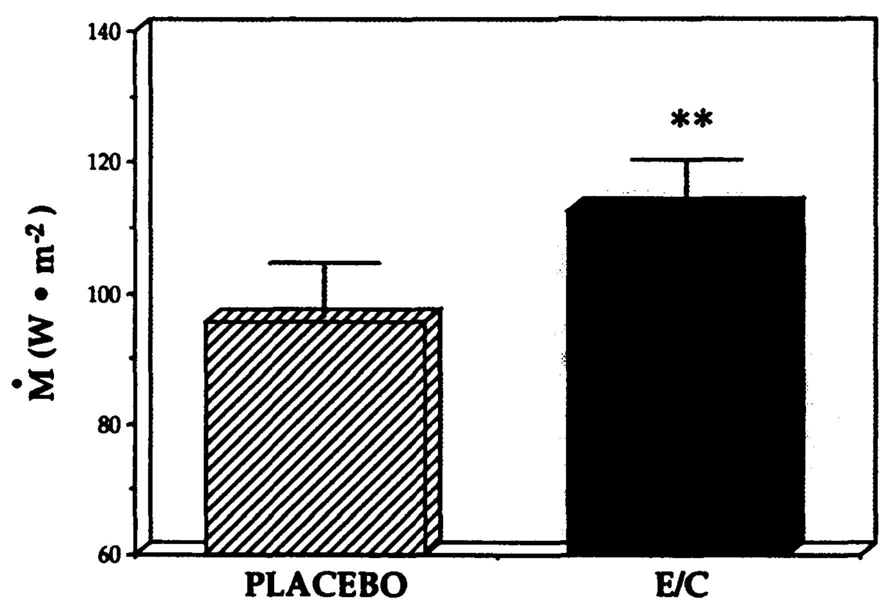

Fig. 4. Influence of Ephedrine/Caffeine ingestion on average heat production in cold-exposed subjects.

is unlikely for two reasons. First, previous trials have mainly used about 300 kcal (1,255 kJ; 20-22, 25-27). Secondly, we have recently completed such a study where subjects ingested as much as 710 kcal (2,970 kJ) in an effort to maximize substrate mobilization in the cold (28). As above, such an ingestion had no beneficial effect on any measured thermal physiology variables, even though it increased CHO *mobilization* and oxidation at the expense of lipid *mobilization* and oxidation. Though energy substrate *utilization* is crucial to fuel M in the cold (29), our data do not support the theory that energy substrate *mobilization* is limiting for M in humans and it is suggested that other factors are required to enhance thermoregulatory thermogenesis, which in turn could reduce the heat debt and thus ameliorate cold resistance. Additional experiments were carried out to explore these factors.

5 EPHEDRINE/XANTHINES MIXTURES IN THE COLD

Recent studies have firmly established that β-adrenergic drugs, such as ephedrine (E), and xanthines (X), such as C and T, significantly increase resting M in humans exposed to comfortable ambient temperatures, either on a short- or long-term basis (30-33). These studies also served to demonstrate the efficacy and safety of these anti-obesity compounds. Whether mixtures of E/X can enhance thermoregulatory thermogenesis and cold tolerance, and by which mechanisms, was examined in two separate studies.

In a first study, the ingestion of E/C (1 mg/kg, 2.5 mg/kg) in the cold significantly increased the overall $\dot{M}$ by 19% compared to the same subjects receiving the placebo ($P<0.05$; Fig. 4; 2). This increment in M was fuelled almost entirely by a large increase in CHO oxidation ($P<0.05$) in comparison with the placebo, with no change in lipid or protein oxidation rates. This was associated with significantly smaller drops in (and thus warmer) T_{re} and $\bar{T}_{sk}$, a lesser body heat debt and slightly higher catecholamine levels.

In another study of E/X in the cold, the ingestion of E/C/T (44, 60, 100 mg, respectively) significantly increased M by 17% over the 3h in the cold, in contrast to the placebo condition (Fig. 5; 34). This was achieved through a significantly greater lipid oxidation and a slightly greater carbohydrate oxidation (Fig. 5). This enhanced thermoregulatory thermogenesis was directly related to a significantly lesser heat debt and slightly warmer T_{re} and significantly warmer $\bar{T}_{sk}$.

These results demonstrate the beneficial effects of E/X mixtures in the cold. Both mixtures significantly enhance thermoregulatory thermogenesis, produce warmer body temperatures and reduce the heat debt (Figs. 4, 5). When compared to other similar cold studies detailed earlier (Table 1), the improvements in important thermophysiological parameters

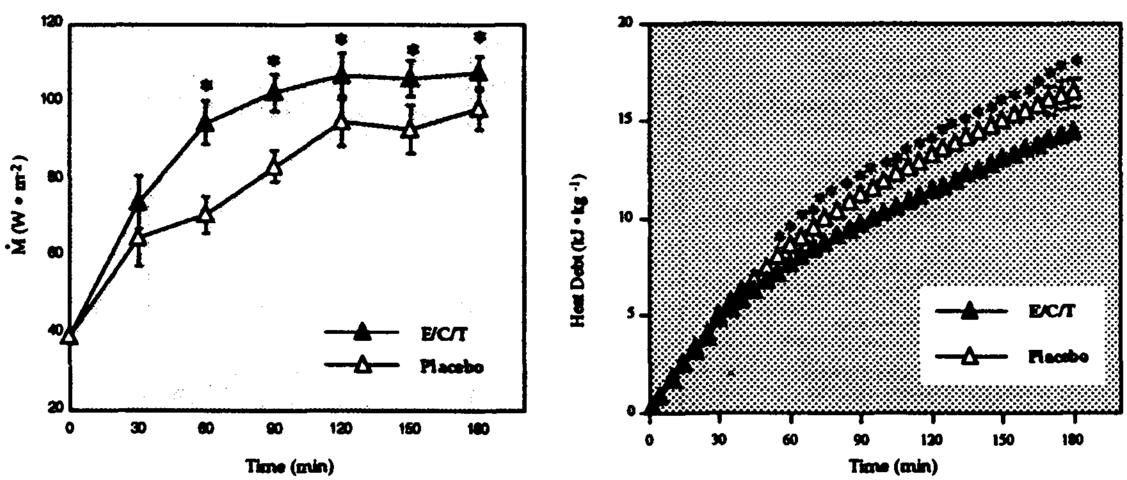

Fig. 5. Influence of Ephedrine/Caffeine/Theophylline ingestion on heat production and heat debt in cold-exposed subjects.

such as the changes in M, dry heat loss (R+C), heat debt (S) as well as ΔT_{re} and $\Delta \bar{T}_{sk}$ appear more favourable with E/X than with the others. This Table also highlights the value of a heat balance analysis and that it should be performed more often since the heat debt appears as a more robust index of cold resistance than T_{re} alone.

The exact mechanism of cellular action of E/X in the enhancement of thermoregulatory thermogenesis is still uncertain, but an increase in sympathomimetic effect is likely. On the one hand, it is well known that E is an adrenergic agonist that stimulates both β and α receptors and can increase plasma catecholamine levels (33, 35). On the other hand, X, such as C and T, act either by inhibition of phosphodiesterase activity, by antagonistic effect at the level of adenosine receptors or by a translocation of intracellular calcium (33, 36). By combining these actions, E/X compounds could thus increase liver and skeletal muscle glycogenolysis, white adipose tissue lipolysis and the activation of the sympathetic nervous system (2, 30-33, 35, 36). It is clear that an increase in either CHO or lipid oxidation would probably be dependent on the actual dosage of E and X used. One thing that is not clear is which particular tissue is responsible for the E/X-induced increase in thermoregulatory thermogenesis. It could well take place in the skeletal muscle, which is a major site of heat production during shivering (see 1, 2) and during the E-induced thermogenesis at comfortable ambient temperature (30). Since E/X do increase heat production without muscular contractions at comfortable ambient temperatures and since E/X increase cold thermogenesis without any evidence of greater shivering (data not shown), it is thus possible that E/X act via mechanisms unrelated to shivering, either at the level of the striated muscle or at the level of the smooth muscle in the vascular bed, as recently suggested (37). These hypotheses require further study.

In conclusion, ephedrine/xanthines mixtures represent at the moment one of the best and safe pharmacological agents to enhance cold thermogenesis and to delay the onset of hypothermia in humans.

6 ACKNOWLEDGEMENTS

It is with great pleasure that I acknowledge again, the expert assistance of Ms. Ingrid Schmegner.

TABLE 1. INFLUENCE OF DIFFERENT COMPOUNDS ON IMPORTANT THERMOREGULATION PARAMETERS IN THE COLD

	M	R + C	S	ΔT_{re}	$\Delta \bar{T}_{sk}$
Ephedrine-Caffeine-Theoph (Vallerand et al. 1993)	↑17%	↑4%	↓12%	↓24%	↓8%
Ephedrine-Caffeine (Vallerand et al. 1989)	↑19%	↑5%	↓14%	↓41%	↓11%
Theophylline-Rest (Wang et al. 1986)	↔	—	—	↓56%	—
Theoph+Substrates-Rest (Wang et al. 1986)	↑3%	—	—	↓56%	—
Theoph-Exercise (Wang et al. 1987)	↑3%	—	—	↓33%	—
Theoph+Subtrates-Exercise (Wang et al. 1987)	↑7%	—	—	↓55%	—
Cold Buster (Vallerand et al. 1992)	↔	↔	↔	↔	↔
Caffeine-Rest (McNaugton et al. 1990)	↑16%	—	—	↔	↑16%
Caffeine-Exercise (Graham et al. 1991)	↔	—	—	↔	↑7%
Caffeine-Exercise (Doubt et al. 1991)	↑16%	—	—	↔	↓3%

Comparisons with a Placebo (%): ↑ Increase; ↓ Decrease; ↔ no change; — not available.
M: Metabolism; R + C: Dry heat loss; S: Heat debt; ΔT_{re}: Change in T_{re}; $\Delta \bar{T}_{sk}$: Change in $\bar{T}_{sk}$.

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TREATMENT OF MILD IMMERSION HYPOTHERMIA BY BODY-TO-BODY AND FORCED-AIR WARMING.

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The purpose of these studies was to test two methods (one traditional, one recent) for treating mild immersion hypothermia.

1) Body-to-body contact has often been recommended for rewarming hypothermia recipients in the field (1, 4, 5, 6). This involves a euthermic individual donating heat to the recipient by direct contact in an insulated bag. However, this technique has not been critically evaluated and may not be beneficial because: there is limited direct contact between recipient and donor; peripheral vasoconstriction may impair heat transfer to the core (2); skin warming may blunt the recipient's shivering response(3); and cold stress to the donor may be excessive. This first study evaluated whether donation of heat by a donor would be sufficient to enhance rewarming of a hypothermic subject (recipient). Six pairs of recipients (5 men, 1 woman) and donors (2 men, 4 women) participated in the study. Esophageal (T_{es}) and skin temperature, cutaneous heat flux, and oxygen consumption (VO_2) were measured. Recipients were immersed in 8°C water until T_{es} decreased to a mean (±SD) of 34.6±0.7°C. They then were rewarmed by one of three methods: a) passive rewarming by the endogenous heat generated by shivering (SH), b) body-to-body rewarming (BB), and c) rewarming with a constant heat source manikin (MAN). Mean afterdrop for the three conditions was SH=0.54±0.2, BB=0.54±0.2, and MAN=0.57±0.2°C (N.S.), and the rate of rewarming was SH=2.40±0.8, BB=2.46±1.1, and MAN=2.55±0.9°C·min^{-1} (N.S.).

2) Forced-air warming (FAW) is a new procedure used for prevention or reversal of hypothermia in surgical patients. In this second study, the efficacy of forced-air warming, for treatment of immersion hypothermia, was evaluated. Six men and two women were twice immersed in 8°C water until hypothermic. They were then

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rewarmed by either: a) shivering inside a sleeping bag (SH); or b) forced-air warming (Bair Hugger® 250/PACU Warming System with 300 Warming Cover, Augustine Medical). Esophageal and skin temperature, cutaneous heat flux and metabolism were again measured. Afterdrop during FAW (0.41±0.23 °C) was ~30% less than during SH (0.61±0.26 °C) ($P<0.01$). The rewarming rate during FAW (2.67±1.2 $°C \cdot h^{-1}$) was not significantly different from SH (2.25±0.7 $°C \cdot h^{-1}$). Skin temperature was higher during FAW by 5°C. Heat production increased by approximately 80 W over the initial 20 minutes of SH, and subsequently declined, compared to an immediate decrease with FAW. During SH heat flux ranged from 30 W early in rewarming, to 50 W after 30 min, compared to -230 W and -160 W respectively, for FAW.

Under our laboratory conditions during body-to-body rewarming, recipient shivering thermogenesis is blunted to the extent that the rewarming rates during heat donation are not greater than during shivering alone. Body-to-body rewarming was not an excessive thermal stress for the euthermic donor. When deciding whether or not to use this method, the possible psychological advantages must be weighed against the human and material resource implications.

Forced-air warming attenuated afterdrop and the metabolic stress of shivering while maintaining an average rate of rewarming comparable to shivering. Forced-air warming is a safe, simple, noninvasive treatment and could be used effectively in an emergency medical facility, and possibly in some rescue/emergency vehicles or marine vessels.

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Nutrition and Hydration Status of Aircrew Members Consuming an Improved Survival Ration During a Simulated Survival Scenario

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1. SUMMARY

Adequate nutrition and hydration can be crucial to the survival of downed aircrews. To determine the nutritional adequacy and palatability of an improved, all-purpose, all-environment survival packet (GP-I) compared to the old survival packet (GP), a field test was conducted using combat survival school students. During a five day survival exercise, 41 aircrew members ate the GP-I and 57 ate the GP. Nutrition/hydration status were assessed from food/fluid intake records as well as changes in body weight. Water turnover was measured in a subset of subjects (n=30) using deuterium oxide. Pre- and posttest hemoglobin, hematocrit, plasma osmolality, urine specific gravity (SG) and ketones were also measured. Acceptability of the two rations was evaluated. Subjects eating the GP-I consumed more Calories; GP-I 774±436 vs GP 642±408 kcal/d. Carbohydrate and protein consumption were similar but the GP-I group ate significantly more fat, 35±21 vs 24±18 g/d. Mean fluid intake was similar for both groups (GP-I 4.3±1.7, GP 4.4±1.9 L/d). Sodium intakes were 1.1 g/d. Weight decreased significantly for the GP-I and GP groups (2.9±1.4 , 3.4±1.7 kg, respectively); changes were similar between groups. Water turnover data indicated subjects maintained adequate hydration as did hemoglobin, hematocrit, and plasma osmolality. Mean posttest urine SG was 1.024±0.007 and moderate amounts of ketones were detected in urine. Both rations received favorable ratings, but the greater variety of the GP-I ration resulted in higher acceptability ratings. We conclude from these results that either ration is adequate, however, the GP-I is more desirable and palatable than the GP.

2. INTRODUCTION

The development of the Food Packet, Survival, General Purpose, Improved (GP-I) was initiated by the Air Force in 1987. The Air Force requested that a survival packet be designed to replace the Food Packet, Survival, General Purpose (GP) which was type classified in 1961 and had not been updated since initially procured. Limited procurement quantities have contributed to problems in obtaining the components (two by three inch compressed cereal type bars), as well as the tin-plate can that were part of the original design.

The purpose of a survival ration is to preserve the physical and mental functions of military service personnel long enough during a survival situation to permit him/her to be rescued and/or to escape or evade capture. The requirements for the GP-I state that it must be lightweight and low volume; be used on land or sea for short periods of time (one to five days); provide optimal nutrition to conserve body fluids and prevent ketosis; and be highly acceptable to help boost morale (1-3). To conserve body water and prevent ketosis, the ration must provide adequate carbohydrate (at least 100 g), limited protein (less than 8% of the kcal), and restricted sodium (one to two g) (4).

The survival packets are provided in flight kits on aircraft, in life rafts, and in remote storage areas. Storage of the food packets can extend for as long as five years, including periods of time at very high temperatures, such as would be found in aircraft sitting on asphalt during the summer. Due to these environmental extremes, the storage requirement for this packet is five years at 80°F and one month at 140°F.

The effects of the prototype ration and its acceptability were evaluated in 98 subjects over a five-day Field Training Exercise (FTX). During the study, volunteers consumed either the GP-I or GP. The overall objective was to determine if, during a short-term simulated emergency feeding scenario, with unlimited water available, the GP-I would adequately support five-days of moderate to heavy physical activity.

3. METHODS

3.1 Experimental Design

The study employed a prospective design. Baseline testing took place at the U.S. Air Force Survival School, Fairchild AFB, WA. The survival exercise and post-experiment testing took place in Colville National Forest. Pre-test assessments were made of height and body weight. During the FTX, food and fluid intakes, and ration acceptability were monitored. Posttest measures of body weight and questionnaire follow up data were collected.

To better assess the subjects' hydration status, a subset of 30 volunteers was studied more extensively. In addition to the above measurements these subjects had the following procedures performed pre- and post-experiment: measurement of activity patterns using an activity monitor; estimation of percent body fat by the circumference method;

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determination of total body water and its turnover rate by administering the stable isotope deuterium oxide (^2H_2O); and venipuncture blood draw for hematology and chemistries.

3.2 Subjects
Test subjects were recruited from two consecutive classes of the U.S. Air Force Combat Survival Course, Fairchild AFB, WA from 13 June through 2 July 1991. Potential subjects were briefed on the nature of the study and those participating provided written acknowledgement of their consent. Two preformed training groups were assigned to eat either the GP-I or GP. All non-participating students ate the ration that their group was assigned. Thirty-eight students (51%) volunteered from the first class and 60 students (68%) volunteered from the second class. Both males and females participated in the study. The GP-I group was comprised of 36 males (87.8%) and 5 females (12.2%). In the GP group there were 51 males (89.5%) and 6 females (10.5%). Subjects from the GP-I and GP ration groups were then randomly assigned into subgroups for more detailed study.

3.3 Operational Scenario
The study was held during the field training exercise (FTX) phase of the U.S. Air Force Combat Survival Course. The course is designed to train aircrew members in Survival, Evasion, Resistance, and Escape (SERE) procedures. Each class lasted 17 days. The first week (days 1-6) involved classroom instruction, days seven through 12 were a FTX, and days 13 to 17 concluded training with additional classroom instruction.

The classroom portions of the school were taught at Fairchild AFB and the FTX was held in Colville National Forest. The elevation ranges from 762 m (2500 ft) to Calispell Peak which is approximately 2072 m (6800 ft). Even though the area is primarily a temperate zone forest, by 1371 m (4500 ft) it becomes subalpine. The steep, mountainous terrain of the forest has a floor covered with large amounts of varied debris, including many fallen trees, rocks, thick brush and undergrowth. The drainage areas are swampy and surrounded by dense vegetation.

Students deployed for the FTX at 0800 via bus to the forest area. The first and second days in the field were spent in static camps and training was done around the site. On the third day the students were given points to find in order to practice land navigation after which they returned to camp. On these "out and backs" students carried all their gear (15-23 kg). On the fourth day of the FTX evasion exercises began. For this segment of the course, the students were divided into two-person teams, camouflaged, and given a number of compass headings and points to find. The instructors tried to "capture" them. Each night the students set up a different campsite while still in "combat mode." The evasion exercise continued throughout the fifth day and the morning of the sixth day. The FTX and evasion phase ended by noon on the sixth day.

The physical activity level of the volunteers was heavy (5). Both classes covered approximately the same distances daily except for day two when the second class walked two kilometers (km) less. The distances covered were cross-country (off-trail) in a four square mile area with the elevation ranging from 762 to 1372 m (2500 to 4500 ft). Subjects were on their feet for the entire 16 hour training day.

3.4 Rations
Table 1 lists the weight (wt), kilocalories (kcal) and total grams and percent of calories coming from protein (pro), fat and carbohydrate (CHO) for the test group (GP-I) and the control group (GP) for the entire five-day study period. In order to give the survival school students the same amount of kilocalories they would have normally received, three GP-Is and four GPs were issued. This provided the GP group with 87 kcal/d more (7%) than the GP-I group. Issuing these extra kilocalories was unavoidable because it was not feasible to break up individual ration packets. Further, course requirements dictated that subjects receive foods that could be preserved and/or made into a stew (i.e. rabbit, steak, onion, and potato). Test volunteers also supplemented their diet with items they foraged. These included porcupine, snake, squirrel, trout, frog, venison, snail and numerous plant foods.

Table 1. Total amount of food issued per subject

	GP-I Group	GP Group
	3 GP-I rations 1 small potato 1/2 small onion 4 oz round steak 2 oz rabbit 3.4 oz tang	4 GP rations 1 small potato 1/2 small onion 4 oz round steak 2 oz rabbit 3.4 oz dry tang
Wt (g)	1023	1160
kcal	5001	5391
Pro	115g/9%	145g/11%
Fat	214g/39%	203g/34%
CHO	672g/54%	748g/56%

Supplemental foods totaled 867 kcal, 61 g protein, 19 g fat, 112 g CHO

The GP-I components are individually packaged in a trilaminate plastic material and protected by a paperboard box. The prototype GP-I used in this field evaluation consisted of five 1" by 3" compressed bars: two cornflake bars, one shortbread cookie bar, one chocolate chip bar, one granola bar, along with one package of hard candy (Charms), instant coffee, sugar and instant bouillon. A roll of wintergreen tablets developed for this ration was unavailable for use in this test; however, it will replace the hard candy in the future. The nutrient composition of the GP-I is shown in Table 2.

The GP components are individually packaged in cellophane material and stored in a tin can. The GP used in this test consisted of four 2" by 3" compressed bars: two cornflake bars, one granola bar, one rice/cornflake bar, instant coffee, sugar, and instant bouillon. The nutrient composition of the GP is shown in Table 2.

Table 2. Nutrient composition, mass and volume

	GP-I	GP
Kcal	1386	1131
Pro (g)	18/5%	21/7%
Fat (g)	65/42%	46/37%
CHO (g)	182/53%	158/56%
Sodium (g)	2.3	1.7
Wt (g)	332	341
Volume (cu in)	26	27

4. PROCEDURES

4.1 Activity Patterns

Computerized wrist monitors (Actigraph, Ambulatory Monitoring, Inc., Ardsley, N.Y.) were used to identify periods of activity and inactivity during the five-day study period. The output of the wrist monitor's piezoelectric motion sensor was recorded in a continuous series of 1-minute periods. Monitors were worn by 13 subjects from the GP-I sub-group and nine from the GP sub-group.

An algorithm for differentiating periods of inactivity and activity from wrist activity monitor data (6) was used to distinguish physical activity from inactivity, where A_i's represent actigraphic measures for a completed minute epoch. Thus A_{-3} is the measure for the one minute epoch completed 3 minutes ago. The activity/inactivity criterion is such that, if S,0.5, then A_0 is scored as active or if $S \geq 0.5$, then A_0 is scored as inactive.

$$S=(-0.001)A_{-5}+(-0.001)A_{-4}+(-0.001)A_{-3}+(-0.001)A_{-2}$$
$$+(-0.003)A_{-1}+(0.007)A_0+(-0.001)A_1+(-0.001)A_2+1.004.$$

4.2 Anthropometric Measurements

Height was self-reported for all subjects, except the "hydration status" sub-group who had their height measured to ±0.1 cm. Body weight was measured for all subjects pre- and post-experiment with foot and headgear removed and pockets empty using a calibrated, digital electronic, battery-powered scale accurate to ±0.05 kg (SECA Model 770, Hamburg, Germany). The clothing worn by each subject was noted and then those specific garments were weighed and subtracted from the airmen's recorded body weight. Body fat (energy store) changes were estimated on the sub-group according to the standard military method of taking circumference measurements (AR 600-9). Three measurements of the abdomen (level of the navel) and neck (below the larynx) were taken sequentially pre- and post-experiment by the same individual using a spring-loaded fiberglass anthropometric tape (Gulick Measuring Tape, Country Technology, Inc., Gays Mills, WI). Percent body fat was then calculated using a formula devised for the Army Weight Control Program (7). Female subjects did not have circumference measurements taken due to privacy constraints in the field.

4.3 Food, Water and Nutrient Intakes

Prior to deployment all subjects were issued pocket sized logbooks (approximately 14 x 10.5 cm) and instructed on how to accurately self-record their daily food and water intake. Subjects were also informed that no additional foods or beverages would be permitted in the field other than those that were issued or could be foraged. Subjects were also instructed to write down all foraged food items and estimate, in household units, the amount eaten. The total amount of water drunk was recorded in one-quart amounts. Total water intake was estimated by summing the amount of water consumed from drinking and rehydrating food and beverage items and the moisture content of foods consumed. At the end of the study period, test subjects were interviewed by a trained dietary data collector to verify the accuracy and completeness of the recorded entries. Self-recorded food intake methods have been used in past ration tests and produced accurate results (8).

Nutrient intakes were calculated by factoring individual food items consumed against known macro- and micro-nutrient values. The nutrient factor file included nutrient composition values provided by the U.S. Army Natick Research, Development and Engineering Center (ration items) and the US Department of Agriculture Nutrient Data Base for Standard Reference (Handbook 8). Nutrient intakes that are reported for this study include: kilocalories (kcal), protein (g), fat (g), carbohydrate (g) and sodium (mg). Since the survival ration is designed to be consumed for periods of less than five days nutrient standards for operational and restricted rations do not apply.

4.4 Measurement of Energy Expenditure

Intake balance energy expenditure was calculated for the "hydration status" sub-group from metabolizable energy intake and the change in body fat (energy stores) during the FTX. Dietary energy intakes were calculated from daily food consumption records while changes in body energy stores were calculated from pre- to post-experiment changes in fat free mass (FFM) and fat mass (FM). Fat free mass was assumed to be 27% protein and 73% water, and fat mass was assumed to be 100% fat. The energy equivalents used for protein and fat were 4.4 and 9.5 kcal/g, respectively (9).

4.5 Measurement of Water Turnover

4.5.1 Measurement Of Total Water Influx By Deuterium Turnover

Deuterium oxide was administered orally (0.10 g/kg body mass; MSD Isotopes, St. Louis, MO) in the morning on day +1 and day +6 of the FTX. Deuterium space was calculated from deuterium enrichments in saliva before and three and four hours after dosing:

Deuterium space = $(A/MW_d)(APE_d/100)$ 18.02 $[1/[R_{std}(E_s - E_p)]]$,

where A = dose in g, MW_d = molecular weight of dose water, APE_d = atom percent excess enrichment of dose water, $R_{std} = 2.005 \times 10^{-3}$, the ratio of heavy to light isotope of standard mean ocean water (SMOW), and E_s and E_p = the per mil (‰) enrichments of the final and predose samples, respectively (10). The second determination of deuterium space was corrected for changes in baseline isotopic enrichment.

First-void urine samples were collected on days -2, +2 and +6 and used to monitor isotope elimination. Total water influx (r_U)(g/d) was calculated from deuterium turnover (k_H),: where $\bar{D}$ is the average of the initial and final deuterium dilution space (11).

$$r_U = (\bar{D} \cdot k_H)$$

4.5.2 Isotopic Fractionation. Deuterium is lost via respiratory and cutaneous evaporation more slowly than is hydrogen (12-13). With no correction, the net effect of this isotopic fractionation results in an underestimate of total water influx. However, fractionation correction factors, which are calculated from the ratio of evaporative to non-evaporative water loss, are usually around 0.99 and may be used to reduce the impact of fractionation on the accuracy of water intake calculations (14). Absolute humidity was determined from wet and dry bulb temperature measurements made three times per day at approximately 0530, 1300, and 2000 hours, and was used in calculating fractionation correction factors (10). Median absolute humidities for weeks one and two were 8.94 and 10.55 mg/L, respectively. Water efflux in $g \cdot m^3$ was calculated from estimates of expired air volume and absolute humidity. Expired and inspired volumes were assumed to be equal; ventilation was calculated as previously described (11).

It was assumed that the clothing worn by the subjects covered 75% of their body and reduced the rate of evaporation through clothed areas by half from the 0.014 $g \cdot min^{-1} \cdot m^2$ rate of evaporation from bare skin at room temperature at rest (15). The net estimated rate of transcutaneous water efflux was 0.088 $g \cdot min^{-1} \cdot m^2$.

4.5.3 Water Influx

Transcutaneous water influx in mg/min was calculated as 180 × (absolute humidity/21.7) × (body surface area), assuming a transcutaneous influx of 180 mg/m² body surface area/minute in adults in a saturated 24 °C atmosphere (16), median ambient absolute humidities of 8.94 and 10.55 mg/L, and a 37.5% reduction in transcutaneous water influx due to clothing. Respiratory water influx was calculated as pulmonary ventilation × absolute humidity.

4.5.4 Metabolic Water

Metabolic water was calculated from the water formed by the oxidation of protein (pro) (1 g pro = 0.41 g water), fat (1 g fat = 1.07 g water), and carbohydrate (CHO) (1 g CHO = 0.60 g water) in foodstuffs and from changes in body energy stores (17). Fat-free mass was assumed to be 27% protein and 73% water. Dietary records, anthropometric estimates of the change in body energy stores, and energy expenditure estimated by the intake balance method, were used to calculate substrate oxidation and metabolic water production.

4.5.6 Deuterium Analysis

The hydrogen isotope abundances were measured on a Finnigan Delta S gas-inlet Isotope Ratio Mass Spectrometer. Briefly, urine and saliva samples were distilled under vacuum into tubes containing zinc reagent. The reduction tube was sealed with a flame and placed in a 500°C oven for 30 minutes to reduce the water to hydrogen gas which was then introduced into the mass spectrometer.

The H_2 was isotopically analyzed against two working standards that had been calibrated against SMOW and Standard Light Arctic Precipitation (18). The results were expressed as the per mil difference from SMOW and corrected for 0.5% memory on the reduction system. The SD of a single analysis was 1.7×10^{-5} atom percent for urine and saliva. Each sample was analyzed in triplicate (Pennington Biomedical Research Center, Baton Rouge, LA).

Isotope enrichments were calculated by taking the arithmetic difference between the per mil enrichment of each sample and the respective predose sample. The ratio of excess isotope is calculated and converted to atom percent excess (APE) (19).

4.6 Urine Chemistries

First-void morning urine samples were collected on all subjects pre- and post-experiment. Samples were collected in 50 cc screw top tubes and analyzed for specific gravity using a refractometer accurate to ±0.001 units (Atago, LTD, UR-1, Tokyo, Japan). Urine dipsticks (Ames N-Multistic, Miles Inc., Elkhar, IN) were used to estimate ketones. The ketone measured by this method is acetoacetate and the scale is calibrated in increments of 5, 15, 40, 80 and 160 mg/dL corresponding to trace, small, moderate, and large amounts of ketones, respectively.

4.7 Blood Chemistries

Pre- and post-experiment fasting blood samples were drawn on the "hydration status" sub-group by venipuncture, using standard aseptic techniques. Samples were taken from an antecubital vein and drawn into a serum vacutainer system. One (5cc) Ethylenediaminetetraacetic Acid (EDTA) tube was used for a whole blood sample and one (15cc) Serum

Separator (SST) tube was used for a serum sample. Hematocrit was determined by use of a heparinized capillary tube and read after spinning for five minutes on a micro hematocrit centrifuge (Model IEC/MB, Damon, Dunstable, England). The EDTA tubes were sent to Fairchild AFB Hospital where a complete blood count (CBC) was performed (Sysmex K1000, Baxter Inc., McGaw Park, IL). After the blood in the SST tube had clotted, the tubes were centrifuged and the serum poured into a 5 ml cryo tube for storage and shipment to Pennington Biomedical Research Center, Baton Rouge, LA for analysis. Glucose, blood urea nitrogen (BUN), creatinine, sodium, potassium, chloride, carbon dioxide, uric acid, total protein, albumin, calcium, phosphorus, magnesium, cholesterol, triglyceride, high density lipoprotein (HDL), low density lipoprotein (LDL), total bilirubin, lactic acid dehydrogenase (LD), creatine kinase (CK), and iron chemistries were performed on serum using an automated chemistry analyzer (Beckman Synchron CX5, Beckman Industries Inc., Fulerton, CA). Three 10 μL aliquotes were removed from the remaining serum and used to measure serum osmolality using a freezing point depression osmometer (Model 5004, Precision System Inc., Natick, MA).

4.8 Ration Acceptability

4.8.1 Field Ratings

Daily food item acceptability for the GP-I and GP was determined using a nine-point hedonic scale in which 9 corresponded to "like extremely," 5 corresponded to "neither like nor dislike" and 1 corresponded to "dislike extremely (21)." The subjects rated each food item in the 5-day logbooks used to record food and water intake and mood.

4.8.2 Final Questionnaire Ratings

Two questionnaires, one for the GP-I group and one for the GP group, were administered on the last day of data collection. Both questionnaires contained similar questions assessing airmen's opinions of their respective rations in terms of acceptability and human factors issues, as well as collecting information on demographics and field conditions. Final questionnaires were administered to every student participating in the survival course who wished to fill out a questionnaire, regardless of whether they participated in the study.

4.9 Statistical Analysis

Two consecutive survival course classes were studied during a two-week period in June 1991. Two-tailed unpaired Student's t-tests were performed on data from these two groups to determine if there were any significant differences between iterations. It was found that there were no significant differences between classes except in weight loss (-4.0±0.6 kg GP; -2.7±-.8 kg GP-I; Δ-1.3 kg). The first class' mean body weight tended to be greater than the second class (Δ3.0 kg); although this was not significant. In addition, the first class walked slightly farther than the second class (2 km per day more during the first two days) and had a slightly more active schedule. Given these few differences, the data from the two iterations were combined to simplify the presentation of the results.

One-way analysis of variance with repeated measures (BMDP2V 1990, BMDP Statistical Software Inc., Los Angeles, CA) was used to analyze ration and water intake data. Two-tailed Paried Student's t-tests were used to test for differences between pre- and post-measurements of individual subjects (SPSS-X 4.1, SPSS, Inc., Chicago, IL) for the demographics, activity patterns, anthropometric measurements, urine chemistries, and blood chemistries. The field acceptability and final questionnaire data were analyzed using SPSS/PC+ 4.1 (SPSS Inc., Chicago, IL). T-tests and analysis of variance tests (ANOVA's) were used to detect differences between groups and within groups over time. The Dixon's test statistic was used to determine if a particular subject's water turnover data could be considered an outlier (20). All results are expressed as mean ± SD. A p-value of less than 0.05 was considered to be statistically significant.

5 RESULTS

5.1 Demographics

The GP-I and GP groups initial physical characteristics are presented in Table 3. No significant differences were found between the groups in regard to age, height, initial body weight, or time in service.

Table 3. Physical characteristics

Characteristics	GP-I (n=41)	GP (n=57)
Age (y)	26±5	25±4
Height (cm)	176±7	177±6
Body weight (kg)	76.1±10.7	76.7±9.5
Time in service (y)	3.8±3.7	4.3±3.8

5.2 Activity Patterns

Actigraph data retrieval rates were 54% (13 issued, 7 valid) and 67% (9 issued, 6 valid) for the GP-I and GP groups, respectively. Data retrieval rates were not 100% due to Actigraph malfunction (7 each) and subject non-compliance (2 each).

The mean number of hours of inactivity for the GP-I group was 6.3±0.8 ranging from 5.0±0.5 to 7.0±0.4 hours. The mean number of hours of inactivity for the GP group was 6.2±0.4 and ranged from 5.9±1.4 to 6.9±1.0 hours. Means were not significantly different between groups.

5.3 Anthropometric Changes

Mean body weight changes are shown in Table 4. Both ration groups lost a significant amount of body weight (BW) (GP-I 3.8% BW and GP 4.5% BW). However, the difference in weight loss between ration groups was not significant.

Table 4. Weight change pre to post-study

	GP-I	GP
Weight (kg), day 0	76.7±9.5	76.1±10.7
Weight (kg), day 6	73.8±8.7	72.7±9.9
Change	-2.9±1.4	-3.4±1.7

Percent body fat was estimated in the "hydration status" subgroup only. Percent body fat declined from 16.8±4.4 to 15.5±4.5 (-1.3±1.3) in the GP-I group and 17.3±5.3 to 15.4±5.3 (-1.9±1.3) in the GP group. Difference in body fat loss between the GP and GP-I groups were not statistically different. Two female volunteers one in the GP-I group and one in the GP group did not have their percent body fat taken because of privacy constraints in the field. These two female subjects lost approximately -1.1 kg.

5.4 Nutrient and Water Intakes

Ninety-three percent (38 retrieved, 41 issued) of logbooks given to the GP-I group and 81% (46 retrieved, 57 issued) of those given to the GP group were retrieved. Retrieval rates were not 100% due to the fording of streams and the extremely wet weather which destroyed some logs and the nature of the evasion and other exercises during which some logs were lost.

The GP-I group consumed significantly more kilocalories than the GP group (Table 5). Mean daily protein intakes in grams were approximately the same for both groups (13.4% total kcal GP-I; 15.6% total kcal GP). Mean daily fat intakes in grams were significantly higher for the GP-I group compared to the GP group and accounted for a higher percent of total calories (40.7% vs 33.6%). Both groups consumed approximately the same amount of carbohydrate accounting for 46.5% total kcal GP-I; 49.8% total kcal GP, respectively.

Micronutrient fortification, except for sodium, is not done for these types of survival rations because of the short time periods of projected use. Mean daily sodium intakes were significantly different between the GP-I and GP groups.

Table 5. Mean daily nutrient intake from all food sources (ration, supplement, forage)

Nutrients	GP-I	GP
Kcal	774±436*	642±408*
Pro, g	26±21	25±22
Fat, g	35±21*	24±18*
CHO, g	90±57	80±54
Sodium, mg	1297±269	974±332*

* P≤0.00
Daily means were derived for each man and then man-means were averaged to get a group mean

Table 6 shows the distribution of kilocalories from the different food sources consumed over the entire five day study. Mean ration intake was significantly more for the GP-I group than for the GP group. The GP-I group consumed 61% of the rations issued while the GP group consumed 48%. Intake from supplemental and foraged foods were similar between groups.

Table 6. Mean total kcals consumed from different sources over the entire 5-day study

Item	GP-I	GP
Breakfast, day 1	772±450	676±425
Ration	2525±781*	2151±877
Supplemental	500±225	462±227
Foraged	270±192	248±210
Mean 5 day total	4067	3536

*P≤0.05
Means were derived for each food type then summed

Both the GP-I and GP groups reported consuming approximately the same amount of water (4.3±1.7 L/d GP-I; 4.4±1.9 L/d GP). Water intakes did not vary greatly during the five-day study period. There were no significant differences between ration groups.

5.5 Energy Expenditure

Mean daily energy expenditure estimated using the intake balance method was 4096±2113 kcal/d for the GP-I group and 5351±2089 kcal/d for the GP group. There was no significant difference between groups. The combined intake balance energy expenditure for both groups (n=25) was 4697±2113 kcal/d.

5.6 Total Body Water and Water Turnover Rate

Of the 30 subjects who were studied more intensively, 24 completed the entire D_2O sample collection schedule. In addition, one subject proved to be an outlier (P≤0.05) using Dixon's test statistic (33). The mean elimination rate (kd) for D_2O was 0.10189±0.01972 the GP-I group and 0.10129±0.02989 for the GP group. Mean total body water did not change significantly pre- to post-experiment.

5.6.1 Water Influx

Total water influx which includes water from food and drink, water of oxidation, and water absorbed through the skin and lungs was 5092±836 g/d for the GP-I group and 4946±1003 g/d for the GP group and (Tables 7). Mean respiratory water influx (r_{bi}) was about 3% and 5% of total water influx for the GP-I and GP groups, respectively. For both the GP-I and GP groups, mean transcutaneous water influx (r_{ci}) accounted for 4% of total influx while mean metabolic water influx (r_m) was about 8% and 12%, respectively. The sum of water influx from these three routes was 824 g/d (16%) for the GP-I group and 1102 g/d (21%) for the GP group. There were no significant differences between groups for any of these measures.

Table 7. Preformed water intake

	Water Influx g/d	r_{bl} g/d	r_{cl} g/d	r_m g/d	Preformed Water g/d	Recorded Water g/d	Difference %
GP-I (n=12)	5092±836	171±78	221±22	423±182	4277±811	4615±944	7±19
GP (n=11)	4946±1003	243±122	234±25	625±286	3880±920	4024±1047	3±17

water influx = total water influx as calculated from deuterium turnover
r_{bl} = rate of respiratory water influx
r_{cl} = rate of transcutaneous atmospheric water influx
r_m = rate of metabolic water production
preformed water intake = (water influx - ($r_{bl}+r_{cl}+r_m$))

For the volunteer group as a whole total water influx was 5022±901 g/d. Respiratory and cutaneous water influx totaled about 8%, metabolic water contributed about 10%, and preformed water intake accounted for the balance. Subject's turnover rates were approximately 10.5% per day.

5.6.2 Preformed Water Intake

Preformed water intake (water intake from food and drink) was calculated from total water influx by subtracting the sum of respiratory water influx (r_{bl}), transcutaneous influx (r_{cl}) and metabolic water influx (r_m). There were no significant differences between groups (4277±811 g/d GP-I, 3880±920 g/d GP).

5.6.3 Comparison With Recorded Intake

For the group as a whole mean preformed water intake, calculated by the deuterium oxide method, and self-recorded water intake did not differ significantly (preformed 4088±867 g/d, recorded 4332±1017 g/d, difference 5±18%).

5.7 Urine Chemistries

The urine sample retrieval rate was 97% (196 observations, 19 missing samples). These missing values were due to the unavailability of test subjects during the second iteration of post-study collection. The mean urine specific gravities (SG) pre- and post-experiment never exceeded 1.030, however there were subjects who were above this criterion for hypohydration. Table 16 shows the number of individuals in each group who had urine SGs above 1.030. The mean urine SG prior to deployment was 1.021±.007 for the GP-I group and 1.022±.007 for the GP group. Mean post-study urine SG for the GP-I and GP groups were 1.024±0.007 and 1.024±0.006, respectively. There were no significant differences in urine SG between ration groups pre- to post-study.

Table 8. Percent of urine samples with specific gravity >1.030

Urine SG >1.030	GP-I	GP
Pre-study	7%(3/41)	11%(6/54)
Post-study	7%(2/30)	23%(12/53)

The frequency of ketones in the urine pre- and post-study are presented in Table 9. For the post-study urine sample the majority of subjects (97% GP-I and 100% GP) had small to moderate amounts of ketones compared to very few (7% GP-I and 2% GP) pre-test.

Table 9. Percent of urine samples positive for ketone

Urine ketones	GP-I	GP
Pre-study	7%(3/41)	2%(6/54)
Post-study	97%(29/30)	100%(53/53)

5.8 Blood Chemistries

Pre- and post-study hemoglobin, hematocrit and serum osmolality values are shown in Table 10. All values were within normal ranges before and after the FTX but did decrease significantly pre- to post-experiment. There were also significant differences between the GP-I and GP groups in hemoglobin and hematocrit measurements pre-experiment.

The majority of pre- and post-blood chemistries listed in the methods section under "Blood Chemistries" fell within in normal physiological ranges at both points. The exceptions were uric acid, bilirubin, creatine kinase (CK), lactic acid dehydrogenase (LD) and aspartate amino transferase (AST). There were no significant differences between ration groups

Blood lipid values for the entire subgroup are shown in Table 11. All mean values were within normal limits pre- to post-experiment but showed large significant decreases.

Table 11. Pre- and post-blood lipid values (n=30)

	Pre	Post	Normal
Cholesterol, mg/dL	188±31	163±27*	140-200
Triglyceride, mg/dL	136±69	68±21*	35-160
HDL, mg/dL	43±11	49±10*	30-70
LDL, mg/dL	118±27	101±28*	65-175
CHOL/HDL ratio	4.37	3.33	4.97

* P<0.05

Table 10. Pre and post-study hemoglobin, hematocrit, and serum osmolality

	n	Hemoglobin		Hematocrit		Serum osmolality	
		Pre	Post	Pre	Post	Pre	Post
GP	14	15.6±0.8	14.7±1.1*	45.8±1.9	43.5±3.4*	290±7	279±6*
GP-I	16	16.3±0.7**	14.9±0.7*	47.5±1.6**	43.7±2.1*	292±6	276±4*

* P<0.05 pre- to post-experiment
** P<0.05 GP vs GP-I group

5.9 Ration Acceptability

5.9.1 Field Ratings

Field ratings for individual foods in the GP-I and the GP rations are presented in Table 12. The airmen were asked to rate each food item on a 9-point hedonic scale where 1 corresponded to "dislike extremely," 5 corresponded to "neutral" and 9 corresponded to "like extremely." Overall, the GP-I received ratings of "like moderately" or better, except for coffee, which received the lowest rating of "dislike slightly." The GP received an overall rating of "like slightly" or better with coffee receiving the highest rating of "like moderately." However only six people drank it. For items present in both rations there were no significant differences between ration item ratings, except for Coffee. The GP Coffee was rated significantly higher than the GP-I Coffee even though the coffees were identical.

Table 12. Mean food item field ratings

Food bars	GP-I	n	GP	n
Granola	7.1±1.3	30	6.2±1.7	6
Cornflake (GP)	-	-	6.2±1.3	40
Cornflake (GP-I)	6.5±1.8	37	-	-
Cornflake/rice	-	-	6.0±1.6	34
Shortbread	7.3±1.3	34	-	-
Charms candy	7.4±1.3	34	-	-
Chocolate chip	7.0±1.8	30	-	-
Coffee	4.9±3.1	11	7.5±7.5*	6
Sugar	6.9±2.4	7	7.4±1.3	22
Soup/gravy base	7.3±1.9	16	7.3±1.3	20

n = Number of students consuming food item
* P<0.05

5.9.2 Final Questionnaire Acceptability Ratings

On the final questionnaire, the subjects were also asked to rate each of the food items in the rations. In all cases, the ratings from the final questionnaire were lower than the field ratings. Table 13 summarizes the final questionnaire results. Many of the students indicated they dislike or do not drink coffee and others were concerned about its diuretic effects.

Table 13. Mean food item final questionnaire ratings

Food Bar	GP-I	n	GP	n
Granola	6.7±1.8	69	3.0±3.5*	3
Cornflake	5.6±2.0	66	4.3±2.3*	57
Cornflake/rice	-	-	4.3±2.3	49
Shortbread	6.6±1.7	67	-	-
Charms candy	7.0±1.7	67	-	-
Chocolate chip	6.8±2.1	68	-	-
Coffee	4.4±2.5	29	6.0±2.0*	28
Sugar	6.4±2.0	30	7.0±2.0	46
Soup/gravy base	7.2±1.8	52	6.8±1.8	48

* P<0.05

5.9.3 Final Questionnaire: Overall Acceptability and Human Factors

Sixty-nine students who consumed the GP-I ration filled out final questionnaires, while 64 students who consumed the GP ration filled out final questionnaires. Table 14 provides summary ratings of overall acceptability, amount of food, variety, taste and appearance of the GP-I and the GP from the final questionnaire. The results show that on a 9-point scale, where 9 corresponded to "extremely satisfied," 5 was "neutral" and 1 corresponded to "extremely dissatisfied," the GP-I was rated significantly ($p<0.01$) higher than the GP for all aspects. The ratings for the GP and the GP-I ranged from 2.3 corresponding to "very dissatisfied" to 6.9 corresponding to "somewhat satisfied."

Table 14. Comparison of mean GP-I and GP characteristics on final questionnaire

Characteristics	GP-I	n	GP	n
Overall acceptability	6.9±1.5	69	4.9±1.9*	63
Amount of food	5.5±2.4	65	4.4±1.9*	61
Variety	6.4±1.9	66	2.3±1.6*	61
Taste	6.4±1.9	66	4.2±2.0*	62
Appearance	6.1±1.9	66	4.4±1.8*	61

* P<0.01

On average, the GP-I group consumed three food bars a day, while the GP group consumed two bars a day. Both groups managed to make their bars last about 4.5 days. Individuals ate their bars either throughout the day as time permitted or at specified mealtimes determined by their own personal predilections. For each item in the GP ration, 40 to 43.9% reported getting tired of chewing the bars, while in the GP-I group only 3.2 to 15.9% reported this.

When asked to rate how hungry they were, on a six point scale (1=Never and 6=Always), during the exercise, both groups reported that they were hungry "fairly often," with ratings of 3.4±14 for the GP-I group and 3.6±15 for the GP group. Twenty-five percent of the GP-I group and 16% of the GP group felt that they ate enough during the exercise. Frequent reasons for not eating in the GP-I group included (students checked all reasons that applied): 26.1% thought not enough food was provided in the ration, 17.4% did not feel hungry and 15.9% got bored with the food. Reasons for not eating enough in the GP group included : 57.8% got bored with the ration, 40.6% disliked the food, 23.4% reported that their bars were broken into crumbs and 17.2% got tired of chewing the ration.

When asked about how easy it was to prepare the ration for consumption, both groups reported being "moderately satisfied" on a 9-point scale. Both groups also reported that the rations were "moderately easy" to "very easy" to use overall. However, both groups indicated that the instructions were "not at all helpful." It is apparent from the final questionnaires that many of the subjects either never had instructions with their rations or lost the instructions before they could read them. The GP group was significantly less satisfied with how easy the ration was to pack and carry than the GP-I group but still was "somewhat satisfied" on a 9-point scale. The ability to eat some of a bar and rewrap it in the trilaminate foil package for the GP-I ration was appreciated by most, others felt the trilaminate foil represented trash that had to be carried out and could not be burned to avoid leaving evidence in cases of evasion from an enemy. No other significant problems were reported with either ration.

Table 15 contains summary ratings for difficulty of obtaining water, how often enough water was obtained, and thirst. There were no significant differences between the groups. Both groups found it "moderately easy" to obtain water, "almost always" obtained enough, but reported being thirsty "sometimes" to "fairly often." These findings correspond to the intake data which showed no difference between groups and that both groups were well hydrated. Obtaining adequate water supplies was not a problem in this study.

In the GP-I group, 66.7% said they drank enough during the exercise, while in the GP group 48.4% said they drank enough. In both groups, the most frequent reasons for not drinking enough were not feeling thirsty or not feeling that more water was needed (10% in the GP-I group and 14% in the GP group).

Table 15. Water procurement and thirst

Item	GP	GP-I
Difficulty of obtaining water*	2.9±1.5	2.7±1.6
How often obtained enough water†	5.0±0.9	5.1±1.0
Thirst†	3.3±1.1	3.3±1.1

* Nine-point scale (1=Extremely Easy and 9=Extremely Difficult)
† Six- point scale (1=Never and 6=Always)

Ninety-six percent in the GP-I group and 100% in the GP group reported that they purified their water. All subjects used iodine for purification. Ninety-eight percent in the GP-I group and 93% in the GP group obtained their water from streams.

Both groups reported adding water to the Coffee and Soup and Gravy Base "sometimes" to "fairly often." There was a low incidence of subjects adding water to the Cornflake and Granola Bars. Several subjects wrote on their questionnaires that they would have added water if they had known that they could.

Thirty percent of the GP-I and 40% of the GP group reported that they heated water several times to prepare the Coffee and Soup and Gravy Base. Thirty-nine percent in the GP-I and 32% in the GP group never heated water for their rations. In both groups, 55% reported using a campfire to heat water. When asked on the final questionnaire whether including a canteen cup or some device like it in the rations was important, both groups thought it was "very important." Several students indicated that it would be helpful if the GP can could be used to cook in if no canteen cup was provided. The original model of the GP can could be used to cook in but the new GP can, because of the materials and lining, cannot be used for cooking.

The students were asked in an open-ended question on the final questionnaire if there was any essential equipment needed for ration preparation or foraging that was not provided in the rations. The GP-I group listed: metal container to cook in, fork or spoon, salt and damp proof box to put the ration in. The GP group listed: a can that can be cooked in, fork or spoon, snare wire, matches, salt and iodine.

6.0 DISCUSSION

The purpose of this study was to conduct an operational field test of the GP-I survival ration prototype and compare it against the current survival ration during a simulated survival scenario. Although the actual physiological and emotional stress that an aircrew member would experience in a true life and death situation cannot be duplicated in a training or experimental setting, the US Air Force Combat Survival School provides aircrew members with a challenging "survival" exercise. The stresses and deprivation of the field survival test combined with an evasion exercise provided a good trial for the GP-I ration.

Although most humans can survive a few days of fasting with little long term consequence, even a small quantity of food can be effective in preventing the acute debilitating effects of total starvation. Further, it can have a profound impact on an individual's morale.

The GP-I was tested against the current military survival ration (GP) on 98 aircrew survival school students during June 1991. The results of the present study demonstrate that the GP-I can sustain aircrew members for five days without adverse physiological effects and is highly acceptable. The detailed results of this study are discussed below by topic area as outlined in the methods section.

6.1 Nutrition and Hydration Status

Subjects consumed only 16% of their caloric needs, causing a 19,750 kcal deficit over the five days (3950 kcal/d x 5 d). As expected with such caloric deficits, subjects lost a significant amount of body weight, a mean loss for the combined groups of 3.1±1.9 kg or 4% of body weight. Due to the short duration of the FTX it is difficult to determine the exact composition of the weight that was lost (i.e. glycogen, lean body mass, fat, and/or water). The estimates, derived from anthropometry, indicate that of the 3.1 kg body weight lost, 35% came from fat free mass and 65% from fat mass. Dehydration could possibly have resulted in some weight loss; however, the fact that subjects had lower hemoglobin and hematocrits at the end of the study, in addition to high water intakes and low urine specific gravities, suggests that they were adequately hydrated and little of the weight loss could be attributed to dehydration.

Of the survival rations issued, caloric intake was only 60% (2525±781 kcal/d) for the GP-I group and 48% (2151±877 kcal/d) for the GP group. This low caloric intake cannot be attributed to just one cause but is a combination of factors that have been observed in past field studies (21). The anorexia (reduced food intake even when food is readily available) seen during this study can probably be ascribe to poor ration palatability, menu boredom, lack of time to eat, decreased appetite due to increased exercise, anxiety due to simulated survival conditions, a commitment to eat only foraged foods, and intentional dieting.

It has been hypothesized that the fuel stores used during the first few days of semistarvation are primarily carbohydrate (glycogen) and protein rather than fat (17). Glycogen reserves consist of approximately 350 g of muscle glycogen and 85 g of liver glycogen (17). Consequently, if an individual were to utilize his total glycogen reserve it would account for approximately 0.5 kg body weight loss. Further, an individual will lose approximately 40 g body protein/d during semistarvation (22). This would amount to approximately 0.3 kg body weight loss. Glycogen and body proteins are stored in an aqueous solution of approximately 3 g water/g of glycogen or protein (17). The weight losses observed during this study were most likely due to a depletion of the subject's hydrated glycogen and body protein stores in addition to body fat stores.

It has long been known that administration of carbohydrate in early fasting decreases nitrogen loss and spares sodium and water by preventing starvation ketoacidosis. In a classic study of life raft rations, Gamble (22) showed that when healthy young controls fasted for six days they lost approximately 400 g of body protein and 1200 ml of associated water. When subjects were provided with 50 g glucose/d there was a substantial reduction of the protein loss. When 100 g glucose/d was given the protein loss was reduced by half, but 200 g glucose provided little increased protection against body protein loss. These data indicate that providing at least 100 g glucose/d will spare body proteins which decreases the urine volume necessary to excrete its by-products. Although subjects in this study only consumed an average 85 g CHO/d, both rations contained well over the recommended 100 g CHO/ration. If the GP-I and GP groups had eaten their entire ration allotments they would have consumed 109 g and 127 g CHO/d, respectively.

The protein content of survival rations is intentionally limited to approximately 8% of total kilocalories to minimize the amount of water military personnel must drink to dispose of nitrogenous waste products. Quinn et al. (23-24) showed in his comparison of protein-free versus protein-supplemented diets that protein added to the 900 kcal basal diet (0 g pro/d versus 43 g pro/d) increased body water loss, did not improve nitrogen balance, produced ketonuria, and was used mainly as a source of fuel. In this study approximately 17% (159 g pro/5 d) of the calories were derived from protein. Ration items provided 6% of calories (38 g pro/5 d) from protein while supplementary and foraged foods contributed the other 11% of total kcals from protein (121 g pro/5 d). To metabolize 159 g instead of 38 g of protein, 968 ml (about 32 oz) of extra water was required. Since maintaining water balance during a survival situation may sometimes be difficult, sparing water by consuming less protein may be important. The trade off between extra calories obtained by foraging and their effect upon water requirements requires a situation-specific evaluation.

The percentage of calories coming from fat was significantly different between ration groups (41% GP-I; 34% GP). A deficit in dietary fat intake relative to fat combustion has little direct or immediate influence on the physiological function or nutritional status. Short-term fat requirements are normally met from a large body fat energy reserves that has no immediate metabolic function, but serves solely as a readily-mobilized energy reserve to meet any shortfall in food energy intake (25). While negative energy balance can lead to starvation over the long-term, fat energy deficits during short-term military operations are of little concern. This contrasts with the more serious consequences that deficits in water and CHO intake can have during life and death survival situations. This inclusion of fat in survival rations beyond that needed to improve palatability, and perhaps satiety, may be counterproductive in that it reduces the mass and/or volume available in the ration for carbohydrates needed to maintain physical and mental performance.

Any sodium consumed in excess of the metabolic requirement will be excreted, thus increasing the urine void volume for that day which adversely affects fluid balance especially when water is scarce. As with protein, a low but adequate amount of this mineral will spare body water by reducing the amount that is needed to excrete excess amounts of sodium. Since water availability is often a problem during a survival situation, the sodium content of survival rations is limited to about 2 g. Subjects consumed an average of 1.6 g sodium/d in this study.

Blood chemistries changed significantly pre- to post-study but most variables remained within normal physiological limits. The exceptions were: uric acid, bilirubin, creatine kinase (CK), lactic acid dehydrogenase (LD), and aspartate amino transferase (AST). Uric acid is formed from the breakdown of nucleic acids and is an end product of purine metabolism (26). An increase in the production of uric acid occurs when there is excessive cell breakdown and catabolism of nucleic acids as would be seen during starvation and/or stress which probably accounts for the elevations in these subjects (26). Bilirubin is produced from the breakdown of hemoglobin of red blood cells (26). Increases in physical activity by untrained individuals have been associated with increased red blood cell destruction (hemolysis) (26). One of the causes could be mechanical trauma inflicted on the capillaries of the feet from marching or running (27). Other factors may include elevated body temperatures, increased blood flow, acidosis, and the effects of catecholamines (28). All these factors could possibly have affected test subjects in this study. Creatine kinase (CK), lactic acid dehydrogenase (LD) and aspartate amino transferase (AST) are all enzymes that are found in high concentrations in skeletal muscle (26). The increased levels of these enzymes in serum of subjects was probably the result of exercise-induced skeletal muscle trauma occurring during the FTX (29).

Blood lipid values were all within accepted ranges. Cholesterol and triglycerides values tended to decrease pre- to post-study. Further, there was an increase in the HDL fraction and a decrease in the LDL fraction of cholesterol. These types of changes have been observed during other field operations (30-31) and during periods of semi-starvation, elevated work levels and weight loss (32).

Adequate water intake is vital to maintaining physical performance and the well being of military personnel during survival situations. Minimum water requirements for survival in temperate conditions have been estimated to be around 1 L water/d (3,17,33-34). Water intakes below 1 L/d will result in physical deterioration. It is generally recommended that soldiers drink 4-6 L water/d to sustain optimal hydration in temperate weather conditions (35). This would include water used to rehydrate food and beverage items, moisture in food and drinking water. Students were educated about the amount of water necessary to maintain water balance and were encouraged to drink plenty of water during their training exercise.

Results of this study indicate subjects consumed adequate amounts of water. Two methods were used. The ^2H_2O elimination method provided valid estimates of group mean water intake relative to the established method of recording water intake by logbook. Water intake by the ^2H_2O method and by logbook records did not differ significantly.

Laboratory measures of hydration status confirmed results of water intake indicating adequate hydration. Total body water, hemoglobin, hematocrit, serum osmolality, serum proteins, and urine specific gravity were measured. None of the measurements reported were significantly different between ration groups. Total body water, serum proteins and urine specific gravity remained relatively unchanged pre- to post-study. There was a significant decrease in hemoglobin, hematocrit, and serum osmolality pre- to post-study which suggests an increase in circulating blood volume. It has been demonstrated that blood volume can increase after continuous, short-term training (36-37). These data suggest that subjects had no hemoconcentration and were well hydrated at the time the study was concluded. Further, both rations maintained hydration status equally well during the FTX.

6.2 Ration Acceptance

The field acceptability ratings for both rations, in the range of 6 to 9, were within acceptable standards. For example, an average rating of 7 or "like moderately" is felt to indicate a very good product by the ration developers (38). The individual food items were all rated above "like slightly," with the exception of coffee. This may have been due to the low number of people who consumed coffee, which was most likely because of personal preferences since water and heating were equally available to both groups. Coffee packets were provided in every ration.

The final questionnaire ratings for individual food items were lower than the field ratings. Ratings for the cornflake and rice and the cornflake bars were virtually identical. Given that the two bars were very similar in appearance and texture, it's possible that the students couldn't retrospectively distinguish the bars enough to accurately rate them individually. However, the field data show that even when the students rated the bars with the identification of their labelled wrappers, student perception of acceptability was much the same for each of the two bars. The GP group was also dissatisfied with the limited variety and since the bars they received were very similar, taste, appearance and overall acceptability ratings were negatively affected. The GP-I had five different bars while the GP had only three bars, two of which (cornflake and cornflake and rice) were very similar.

The relatively lower final questionnaire ratings, compared to field ratings, are typical of other studies (39). Previous work (39) has shown that final questionnaire ratings are predictably lower than field ratings as an effect of the subjects rating retrospectively and indicating dislike for items they might have avoided eating, and therefore avoided rating, in the field.

The final questionnaire indicated that the students thought a survival ration was a good idea and would help them in a true survival situation. This group did not care for coffee in

the ration, as would have preferred beverage base, cocoa, powdered milk or extra soup mix, possibly because of the high number of people who were not coffee drinkers. Also the diuretic effect of coffee concerned some, but it has been determined that one packet per day would not produce excessive diuresis. Because many of the younger military personnel do not drink coffee and prefer to have some other type of beverage, the coffee should probably be replaced by some hot and/or cold beverage.

Students also expressed a desire for less cereal and candy and the addition of a salty item, such as jerky, dried meat, dried fruit, or peanut butter and crackers. The request for such an item was taken into consideration. However, the nutritional content of the ration has been reviewed by the National Academy of Sciences Committee on Military Nutrition Research (4) which determined that protein and sodium must be restricted to conserve body water and prevent ketosis. Therefore, the inclusion of meat, salty snack items or salt packet may cause excessive body water loss and are not a viable options. The soup and gravy base, which was found to be highly desirable in these tests, provides the limited amount of sodium required. A dried fruit product would provide extra carbohydrate and little or no protein or sodium which is desirable in this type of ration. Unfortunately, dried fruit, which has a longer shelf life than other types of fruit, does not have the shelf stability which is required in the GP-I. Also, the volume of thermostabilized fruits is above the limit for the GP-I.

It was also apparent from the final questionnaire that there were some problems with the instructions on the rations. Many students did not realize that they could add water to some of the bars to make them more cereal-like. This may have also affected the ratings for acceptability and variety because the students were not able to fully utilize the rations. While instructions for rehydration are not provided on the GP metal container, they are provided on the GP-I box. Unfortunately, due to the extremely rainy weather conditions during the study, the GP-I paperboard disintegrated. Adding a water resistant coating to the box would eliminate this problem. Also, rehydration instruction should be provided on each applicable bar package. The instructions were printed on the outside of the GP can and the GP-I instructions were pasted on the box. Perhaps putting instructions right on the bar packaging itself would help. This would prevent the instructions from getting lost if the ration is taken out of the container and divided up, which would probably happen in a survival situation.

On the final questionnaire, the students particularly indicated that inclusion of a container to cook in would help prepare the ration. A high number of subjects in both groups reported heating water to prepare their coffee and soup and gravy base. The original packaging of the GP was a tin-plated, key-opened can that could be used as a survival aid for heating water and cooking food. However, this can is no longer available. Therefore, the packaging was changed in 1987 to an aluminum, pull-top can that contains four - two by three inch compressed, cereal type bars, wrapped in cellophane. This can is no longer readily available for procurement either and is supplied by a sole source manufacturer who is considering replacing it with a plastic can. Furthermore, the required inner coating of the can flakes off when used for cooking. If the can is heated without adequate liquid, toxic vapors are released. For this reason airmen are asked not to use the can for cooking. In addition, complaints have been received that during rough handling, it easily dents and the lid often breaks. The components of this can are wrapped in cellophane, which does not provide an adequate barrier to light, oxygen and potential contamination, should the integrity of the container be compromised. In addition, both the tin-plated and aluminum cans are sized to contain two by three inch bars which are no longer readily available for procurement.

Due to problems with the can and components, new packaging was designed for the GP-I. Each bar is individually wrapped and vacuum sealed in a trilaminate material which is waterproof and impermeable to light and oxygen. The six bars and supplements are contained in a paperboard box and packaged 24 packets to a shipping case. While this box cannot be used for containing or heating water, it is readily available for procurement, can be resized (if necessary) and is inexpensive. For these reasons the military services have approved and adopted this packaging and will recommend that a canteen cup or similar type utensil be provided for cooking/heating purposes.

Overall both rations were nutritionally adequate and did not adversely affect hydration. The improved survival ration (GP-I) was, however, more palatable which in itself is sufficient grounds for recommendation.

7.0 CONCLUSIONS

Both rations had similar effects on body weight loss and hydration status. The GP-I group consumed significantly more kilocalories in the form of fat. The extra fat consumed during this FTX probably moderated the body weight loss but had little effect on either physiologic response or nutritional status of the subjects since short-term energy deficits can be met by using body fat stores.

The individual foods in both the GP-I and the GP received acceptable ratings. The greater variety of the GP-I resulted in more positive ratings than the GP. Therefore, the GP-I, with improvements, is the ration that should be used in the future. The coffee should be replaced with another hot and/or cold beverage powder. Rehydration instructions should be printed on each bar wrapper. The GP-I paperboard box should be replaced with either a can or some type of water resistant box to prevent disintegration of packaging.

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THE POTENTIAL OF NEW TEXTILES IN IMPROVING SURVIVAL PROSPECTS

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SUMMARY

Modern armed forces, as in all periods of history, are strongly dependent on protective equipment and use technology to achieve this aim. Human survival may depend on natural factors (such as cold or heat, storms or flooding, etc.) or on being expopsed to hazards originating in human activities, as in warfare or accidents. Among the arsenal of protective aids, clothing has long been a well-recognised asset.

Substantial developments in new textile fibres and in fabric construction techniques have recently occurred, resulting in greatly improved fabric or garment properties when compared with more traditional production lines. Although strength and chemical resistance are often the principal aims of the new work, consequential advantages (such as improved resistance to heat flow, flammability, moisture vapour transmission or entrapment, weight, thickness and similar bulk properties) can result. The possible application of these developments to aircrew or support staff use, with beneficial effects on both comfort and survival prospects, is worthy of serious consideration.

The paper surveys briefly the role of textile materials in enhancing comfort and survival prospects, in both cold and hot climates, identifying the fibre, fabric and textile construction factors of critical importance. An examination of the interaction between these factors, showing how they enhance or interfere with one another, is also carried out in outline.

Selected new textile fibres and fabric construction or finishing techniques are then analysed to determine how their novel characteristics can improve their cold- or hot-weather performance, with a prediction in each case of how the advantages derived from their incorporation may potentially be of use in improving aircrew or ground support staff clothing applications.

1. INTRODUCTION

Modern armed forces are dependent to a considerable extent on technology to maintain them in a state of preparedness. In addition, their effectiveness may occasionally be put at risk by unexpected events, such as an accident or a freak weather situation, which can affect drastically the chances of survival of an individual.

For this reason, the matter of protection is high on the list of military priorities. It is crucial, both for the aim of winning battles and for the preservation of morale, that military authorities should be perceived as attempting to

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preserve life and health for all personnel as far as possible. One of the major aids in this intent is the judicious use of textile materials in the form of protective garments, and this application of clothing has been accepted for centuries.

In recent years, however, we have seen the development of a wide range of new textile materials, and this development should be taken into account when planning protective clothing for military purposes.

2. SURVIVAL PROSPECTS

The survival of a human being may occasionally be at risk for a number of possible reasons. For aircrew or ground support staff, exposure to intense cold (in the presence or absence of water) or heat, to radiation of various kinds, to mechanical force, and to chemical or biological agents are the major risk factors. The person in danger of death, for instance, may have baled out in the Arctic or in a cold ocean, with delay in rescue forced by distance or weather conditions. Alternatively, he may be subjected to fire, either in the cockpit or in a refuelling accident, or to the effects of conventional, chemical, microbiological or nuclear weapon attack.

The chances of survival from such hazards depends entirely on how effectively the cause of the hazard comes into contact with the human being. The basic means of providing protection are either to prevent the harmful agent from being produced, or to isolate the human being from the source of harm. When there is no possibility of achieving the former aim (in cases where enemy action or unforeseen accident or weather conditions are responsible, for example) then there is no alternative but to accept the need for isolation. This may be accomplished by removing the human being to a safe distance but, where this is impractical, then the provision of some kind of barrier is the only recourse.

In theory, complete protection can be provided against most or all of the above-listed dangers, but the provision of such protection may well impose an unacceptable limit on the dexterity or mobility of the human being, or may reduce survival prospects for some other, totally unrelated, reason, such as by asphyxiation, or by heat stress from perspiration. The barrier may be of any appropriate type. To protect against explosion or radiation, for instance, a massive obstruction may be interposed between the human being and the source of danger to prevent the effects of blast or nuclear material from harming the individual at risk. This type of barrier, unfortunately, totally restricts any kind of movement on the part of the protected person, so may be unacceptable in many practical cases. In contrast, complete protection against harmful chemical substances can be achieved, again in theory, merely by totally enclosing the human being in a plastic envelope which is inert to attack by the substance. Once more, though, this protection is useless, since the person inside the protective container cannot breathe and, even if oxygen is supplied, will be unable to survive because of an inability to dispose of body heat by perspiration.

Thus, the provision of protection must be tempered by care to ensure that human comfort needs (which can become

survival ones in the limit) are met.

3. COMFORT NEEDS

Comfort may be regarded as a pleasant state of physiological, psychological and physical harmony between a human being and the environment. It is usually only noticed in its absence, but our minds and bodies are constantly working to maximise our comfort level without our awareness.

To provide an acceptable comfort level, then, it is necessary that a human being should be at the correct body temperature, should not be subjected to harmful bodily contact (with, for instance, sharp or abrasive objects and corrosive chemical reagents), and should not suffer from major mental stress. If these and similar conditions are not met, then discomfort is experienced and the person suffering it will be unable to function efficiently, a drawback which may clearly be critical in many situations where members of the armed forces are found.

In addition, discomfort can, in the limit, involve the risk of death from other than enemy action. Brief exposure to cold seas or hot sun, for instance, can be invigorating or relaxing, but extended contact with either one can lead to death, by hypothermia or heat stroke respectively. Similarly, mental stress may be exciting on occasion, but its continuing presence can lead to insanity, or even death, if its application is severe enough.

4. THE DILEMMA OF PROTECTION AND COMFORT

Thus, there is a dilemma between the two conflicting aims of satisfying comfort and protection needs. Isolation can give protection, but only at the cost of limited mobility or a risk of death. The examples provided above are extreme cases, but the same type of compromise must be faced in virtually all instances where protection is needed. A firefighter or police officer wearing protective clothing is not able to move or escape as quickly as an unprotected one. A forest worker wearing heavy gauntlets cannot manipulate chain saws or other tools as effectively. An agricultural labourer wearing garments for spray-resistance cannot work for long periods at a stretch because of thermal discomfort. A seaman in oilskins cannot move with great agility round a boat deck. A surgeon in a rubber apron becomes overheated and has to discontinue an operation temporarily for fear of exposing the patient to risk because of lost concentration. A lineman repairing electric wires, wearing heavy rubber gloves for protection from shock, may be tempted to remove them to give him better manual dexterity for handling wires or climbing posts. The goggles worn by a welder, a motor-cyclist or a skier reduce peripheral vision considerably, hampering efficient functioning at the task in hand.

In most cases, then, the existence of a dilemma, and the need to seek a compromise solution, must be borne in mind when considering the design of protective equipment. One of the many ways in which this type of compromise is sought is by the use of textile materials for protective clothing, and a range of products expressly developed with this end-use in mind is already in existence. Newer fibres and construction techniques currently in the process of development should therefore be analysed to

determine how they can improve the needs for protection without sacrificing comfort.

5. SURVIVAL NEEDS

In developing protective garments against a variety of hazards, it is necessary to match the risk to the type of property which can reduce it. For the purpose of this paper, aimed primarily at aircrew and ground staff protection, it is assumed that eight kinds of risk should be considered. These are, not in any order of assumed importance:-

(a) protection against cold, but relatively dry, conditions (such as Arctic exposure)

(b) protection against cold and wet conditions (as when a pilot has to bail out at sea)

(c) protection against high temperatures at close range (in the event of a fire or explosion)

(d) protection against high mechanical forces (occurring possibly on impact or by gravitational acceleration)

(e) protection against high abrasion (as when the body moves quickly while in contact with a rough surface)

(f) protection against radiation (from high-intensity light or tropical sunburn or radioactive contamination)

(g) protection against chemical or biological agents (when handling toxic materials and in germ or chemical warfare conditions, for instance)

(h) protection against electrical shock, either from contact with a current source or by the generation of static charge from repeated contact and separation of surfaces.

In addition, it is assumed that there are relatively minor comfort needs to be met. The absence of these needs will not lead directly to life-threatening situations but may become dangerous if tiredness, distraction or inattention result from their lack. It is important to note that the psychological aspects of comfort may need to be taken into account in establishing the acceptability of any proposed garment, since a protective system which is felt to invite ridicule for the wearer (if it is perceived as not "macho" or "cool", etc.) will be discarded at every possible opportunity.

Thus, the design of any protective garment system is a complex task. It will almost certainly be impossible to provide protection against all of the above conditions at the same time, so a compromise must be adopted, based on priorities established by prediction of the exposure conditions to be met by the wearer.

6. TEXTILES AND PROTECTION

Textile materials are extremely versatile. They can be made in almost any weight, shape, size or thickness desired, so that they are adaptable to any body size. They can be provided with a wide range of mechanical or chemical properties. They can be made with high or low flexibility, are easy to colour, cut and tailor, and lend themselves to virtually any design criteria. They can have high or low values of air

permeability, water resistance, moisture vapour transmission, thermal behaviour, strength, abrasion resistance and other properties relevant to the provision of protection and/or comfort.

In theory, then, a textile product can be designed to provide protection against most types of hazard, or to give a range of comfort aids. As in the general case, though, the two requirements are often incompatible and compromises in design have to be made. This situation has long been accepted, but recent developments in the textile field mean that there are now a considerable number of new fibre types, and a relatively small number of new production techniques, on the market.

Some of these may be of use in enhancing protection while allowing the wearer of garments made from the fibres, or with the new techniques, to remain more comfortable. Unlike the rapid mushrooming of synthetic fibre products earlier in this century, the growth has not been entirely fueled by normal market demands. The major reason for the change from previous scenarios is one of cost. The expense of developing new fibres is so great that most manufacturers would hesitate even to consider such a course of action without the driving force of modern-day needs.

In particular, end-users for whom cost is not critical have been the source of funding for the extremely high price of introducing new materials. The aerospace industry and military establishments, with urgent needs which cannot be met by existing textiles, have been able to fund research into the production of novel materials without concern for cost.

The principal reason for the high costs is the fact that new fibres are difficult to develop, either because the technology is not known or because it is complex. As a result, many approaches which appear to be theoretically sound may not, in fact, lead to a practical end-product. Thus, the cost of research which produces a successful fibre may well include money spent on failed attempts preceding the success. It follows that everyday consumer demands will probably never again lead to a new product, though after the new material is developed, of course, it may well ultimately find uses in a range of consumer markets.

A combination of these two aspects (high research purchasing power and consumer demand) of development brings about the need to find materials for enhanced protection of military personnel. It provides a good reason for research into possible new fibre types, and it is a valuable exercise to consider carefully the characteristics of the new materials or processes, developed recently, in the context of protective clothing. This paper is an attempt to examine this aspect of the development situation. The approach to be used is to establish the textile properties necessary for providing comfort and/or protection of various types, then to see how these needs compare with the properties possessed by the new fibre types or production techniques.

At this point, it is appropriate to examine the textile properties which will maximise the ability of a garment made from the textile to provide protection against

each of the types of hazard listed, together with a consideration of the costs (in terms of comfort) to be paid for this protection.

In cold climates, a textile needs to have high thermal resistance, so that loss of heat from the body is slowed down as far as possible. This property is achieved by increasing enclosed "dead air" spaces to prevent air from passing easily through the fabric to carry away body heat. Dead air space is enhanced by using irregular fibres, formed into loosely twisted yarns spaced closely together, by making the fabric thick, and by raising or brushing its surface to increase hairiness. The cost of incorporating these changes is mainly a loss of strength and abrasion resistance, so that the durability of the garment may be reduced. In addition, a thick garment tends to be heavy and cumbersome, so that the burden on the wearer is increased and mobility or dexterity (both of which can be crucial in warfare or Arctic survival) may be affected. Itch or other forms of skin irritation may also be a factor to consider if the raised hairs contact the body directly.

For protection against high temperatures at close quarters, flame resistance and heat insulation (the latter achieved as above) are both necessary. Selection of the optimum fibre type is critical here, since any garment which burns will harm the person wearing it. A major need is to prevent concentration of the heat, since this can produce localised burning of the body beneath the fabric, so a high thermal conductivity is an advantage for the outer surface of the system, in conjunction with the low conductivity within it. High thermal conductivity is obtained only by selection of a conducting material as a part of the fibre assembly. The combined nature of such a system may well necessitate a high weight, with all its disadvantages again, and an impedance to moisture vapour transfer.

For protection against high mechanical forces, an ability to absorb and dissipate energy rapidly throughout the structure is needed. This behaviour is enhanced by increasing the thickness of the structure, by having a multilayer system, by close spacing of the yarns or other components of the fabric and by using fibres with high breaking energy but low energy recovery, so that the localised effects of impact are dissipated extremely quickly, before a projectile can penetrate the textile structure. This may well involve a cost of high weight, overheating of the body, and a cumbersome garment system, all of which tend to make movement difficult.

The provision of abrasion resistance is similar in nature, since the requirement is for the same kind of fibre, with good resistance to fracture and an ability to dissipate energy, but incorporated this time into a garment with an ability for the yarns to move freely to distribute energy. This change will, of course, increase air permeability, thus reducing thermal insulation and liquid water resistance while enhancing moisture vapour transmission.

For radiation protection, the bulk of material is once again the vital factor, so that a thick textile with many layers and tightly-interlaced construction will be most effective. It should be noted,

though, that textile structures in general are not effective against radioactive sources, so must be used in conjunction with some other form of material (like lead sheets, for instance) to guard against radiation damage of this type. As before, thickness, bulk and weight bring about problems of loading, heat discomfort and lack of mobility or dexterity, all of which will be heightened by the presence of lead sheets or similar radiation-blocking devices.

Chemical or biological hazards are more complicated to resist. They demand a structure which is impermeable to the flow of liquid or vapour, and which will thus be associated, as mentioned earlier, with great difficulty in providing heat and moisture outlet. The wearer will, in consequence, not be able to breathe or perspire freely, so that physiological stability (and possibly survival) will be at risk. Furthermore, the fibre type of which the textile is made will have to be resistant to the action of the agent to which it is exposed, and also to any accidental damage in the form of tearing or abrasion into holes, so that penetration of the harmful agent into the interior of the structure cannot take place.

The matter of electrical shock involves two separate factors. For resisting the flow of current electricity, good electrical insulation is needed. On the other hand, for the prevention of static shock (which is not normally fatal in a healthy human being, but which can bring about a fatal accident if it causes loss of attention or control when a dangerous burden is being carried or if, say, a flammable solvent is being handled), a material with good conductivity is preferred to remove the high charge density from the vicinity of the body as quickly as possible. As is the case for high-temperature exposure, if both types of electrical hazard are likely to be encountered together, a combination of high surface conductivity and high bulk insulation in the interior of the structure will be needed.

Thus, it is evident that compromises will almost always have to be made, with the exact properties needed in the protective system being designed to meet a specific set of circumstances. A second class of compromise, in which comfort needs may have to be sacrificed to some extent, will also be required.

7. NEW MATERIALS

In recent years, a number of new textile materials have been developed, and it is feasible to examine their properties to determine whether they are able to meet the needs of protective clothing better than existing ones do. There are approximately sixty of such potential materials. They may be classified into four distinct groups, those in which the new fibre is a modification of an existing one, those which are not yet commercially available, those which are unsuitable for protective garment use for various reasons (usually because they are designed for a specific end-use which necessitates properties making them incompatible with this application, for example) and those which are truly new.

The fibres which are "new" in the sense that they are a recent addition to the materials available include (in alphabetical order, with their manufacturers, and not intended to imply any preference) **aramid**

(Akzo, Du Pont, Enka, Lenzing, Rhone-Poulenc, Teijin and Unikita), **carbon** (Celanese, Hysol, Kureha, Nippon, Sigri, Stacpole, Tray and Union Carbide), **phenolic** (Courtaulds, Saint-Gobelin-Isover and Toyo Menka), **polyacrylate** (Courtaulds), **polybenzimidazole, PBI** (Hoechst-Celanese), **polyetheretherketones, PEEK and PEK** (Hoechst-Celanese, ICI and Teijin), **polyetherimide**, PEI (Akzo, GEI and Teijin), **polyphenylene sulphide, PPS** (Bayer, CIBA-Geigy, GEP, Hoechst-Celanese, Phillips, Luxilon, Shakespeare, Solvay, Teijin and Toyobo), **polyimide** (Lenzing and Rhone-Poulenc) and **polyoxamide** (Snia),

Fibres which are a modification of those already in existence (and which should be used to replace them if their properties are more suitable) include new forms of **acrylic** (Courtaulds and Toyobo), **cellulosic** (Courtaulds), **chlorofibres** (Rhone-Poulenc), **polyamide** (Atochem, DSM, Du Pont, Rhone-Poulenc and Teijin), **polyester**, including an aromatic copolymer (Hoechst-Celanese, ICI, Montefibre, Rhone-Poulenc and Sumimoto), **polyethylene** (Allied Signal, DSM, Mitsui and Snia) and **polypropylene** (Courtaulds, Drake, BTF, Bonar, Teufel-Berger, Polisilk and Rifil) fibres.

Other new fibres found in the literature, such as ceramic, glass, liquid crystal polymers, metallic, polytetrafluoroethylene, polyvinyl alcohol, quartz, and silica, may be dismissed from further consideration because of incompatibility of various kinds with, or unsuitability for, the intended end-use, and a few remaining fibre types noted, not mentioned to date, are still in the experimental state, and are unlikely to appear commercially for a decade, if at all.

8. FIBRE PROPERTIES

In order to establish the usefulness of these new fibre types in protective clothing applications, it would be necessary to carry out an investigation to determine how they compare with more traditional ones. Because they are numerous and have such different characteristics (usually developed for specific end-uses), it is informative to examine the nature of each type individually, to determine whether any of the critical properties for protective garment purposes are present.

The properties which are most critical for military purposes, in the context of a conference focused on the support of air operations under extreme hot and cold weather conditions, are primarily those providing or maintaining comfort in difficult climatic situations.

In the former case, any protection must be provided with a minimum of weight and the garment should resist potential disintegration in the presence of high-intensity light, water (in the form of rain and/or perspiration) and abrasion. Clearly, there are incompatible needs here. Light weight fabrics tend to abrade and wear more rapidly than heavier ones, and tend to be less of a barrier to radiation or water. In addition, of course, the other protective needs (from impact, electric shock and fire, for example) may also tend to be met less readily if a thinner fabric is used. The vital need, then, is for an initially high value of mechanical integrity (including strength and abrasion resistance), in a fabric of light weight, which is

maintained after ultraviolet exposure.

For cold-weather protection, thermal resistance is the most crucial factor. This tends to be enhanced by the use of many layers of clothing, but this step leads to an impaired mobility and dexterity, so compromise is once again needed. There is also a need to prevent the condensation of moisture from perspiration inside the fabric structure during periods of intense activity, since the high thermal resistance will be reduced or lost by this change. Again, too, the properties must be provided in a manner which allows them to be retained, with no diminution after use in conditions of high ultraviolet exposure, abrasion and perspiration. Thus, for both hot and cold situations, a strong fabric with good resistance to climatic and use conditions is needed.

In addition, there will be secondary critical requirements, depending on the precise end-use envisaged. In maintaining the garment, the ability to dye, launder, tailor and repair the material may be important, as also may its resistance to shrinkage, chemical agents, or electric current. A literature search for the purposes of establishing the properties of new fibres should therefore identify those which might be worth investigating further.

Most of the fibres are strong, but there is little information published on abrasion resistance, mainly because the fibres are newly-developed and the work of investigating this property (except as noted below) has not yet been carried out. Fibres found to have low tolerance to light exposure in their currently available forms include aramid, phenolic, polyetheretherketones (both PEEK and PEK), polyetherimide (PEI), polyphenylene sulphide (PPS), and aromatic copolyester. In addition, aramid, carbon, phenolic and oxidised acrylic fibres are difficult or impossible to dye, so should be eliminated from further consideration if this is a crucial requirement (because of uniform or camouflage colouring needs, for instance) in protective garment production. The fibres remaining after eliminating these "unusable" ones may then be subjected to more detailed analysis, with results summarised below.

9. "NEW" FIBRE TYPES

(a) polyacrylate is a flame-retardant material especially developed for non-woven fabric production. It is used most commonly as a flame barrier, and no information about its strength or abrasion resistance has as yet been found, though these properties are expected to be satisfactory.

(b) polybenzimidazole (PBI) is also flame-retardant, possessing high resistance to chemical attack and to degradation by heat. It has excellent abrasion resistance, but is very expensive.

(c) polyimide is again flame- and chemical-resistant, though it suffers from high shrinkage on heating. It is currently used in the manufacture of reinforced panels and has only recently apeared in sufficient quantities for commercial fabric production.

(d) polyoxamide has relatively high absorbency and is very soft, making it a luxurious material. It has a high tensile strength, with good elongation behaviour, and is easily dyed by a variety of processes. Printing is difficult, because of its absorbent nature, so the manufacturers recommend that it should be used only in solid colours or in a yarn dyed fabric. No information has yet been found on its abrasion resistance properties. It is currently used mainly in blends, with natural or synthetic fibres, to reduce the cost of articles made from it.

10. MODIFICATIONS OF "TRADITIONAL" FIBRE TYPES

The fibres which may be regarded as modified versions of those existing already should next be considered, as follows.

(a) acrylic (Imidex) fibres, made by Courtaulds, are flame and chemical resistant, and have a high absorbency, but relatively low strength.

(b) chlorofibres also have a low tensile strength and moisture absorbency, and soften at low temperatures, so would easily be marked or destroyed by cigarette heat or hot engine cowlings, for example.

(c) cellulosic (Tencel) fibres, also from Courtaulds, have only recently been made commercially available, but the manufacturers are looking for potential field trials and use of the fibres may be worth investigating. They have high strength, elongation and absorbency, but no information is apparently published yet on abrasion and light resistance.

(d) high-tenacity polyamide has high temperature stability and strength, but, once again, no information on abrasion resistance is published. Since normal polyamide is very subject to light degradation, this version may suffer from the same fault.

(e) high tenacity polyester has extremely high strength and retains this property at high temperatures. Its cross-sectional strength is low, so some care may be necessary during manufacture. One source mentioned in passing that it appears to have poor light resistance, a surprising fact for polyester and one which should be checked, either by testing or by contacting the manufacturers, before eliminating it from the list of useful types of polyester. It is, though, costly to produce, so may be eliminated on these grounds.

(f) high modulus polyethylene exhibits very high tensile strength, good elasticity and excellent resistance to chemicals and weathering (as does polypropylene to a lesser extent) but both have a fairly low melting point, which may again cause problems from lighted cigarettes or hot engine parts. One source mentioned some concern about creep (which could affect dimensional stability), but others made no observation on this point.

11. SELECTION OF FIBRE TYPE FOR MILITARY PROTECTIVE APPLICATIONS

It is clear that, for successful incorporation of a fibre into a protective garment, the initial properties must be acceptable and, also, the critical factors of light fastness and abrasion resistance must remain high over the life of the fabric.

With these points in mind, the fibres mentioned above, together with existing "traditional" ones (such as polyamide, polyester, acrylic, modacrylic and polyolefin) can now be examined more carefully. Of the traditional fibres, polyamide has a well-known tendency to lose abrasion resistance drastically when exposed to light, and it is probably this property which is mainly responsible for the shortened life of current products made from this fibre. The conventional type of polyamide should therefore be eliminated from further consideration. Polyolefin has a low melting point, resulting in the potential for easy damage when a cigarette is dropped on it, so may also not be suitable for the end-use. Similarly, polyimide (which is not likely to be available in commercial quantities for some years), chlorofibres and high modulus polyethylene or polypropylene (which all soften too easily, so are likely to suffer damage) are all dubious candidates for protective garment manufacture. In addition, high-tenacity polyamide (which is suspected likely to have poor abrasion resistance after prolonged light exposure) should be regarded as less promising.

Thus, seven fibres with possible application in this field remain to be discussed. These are, again in alphabetical order without indication of preference, acrylic, cellulosic, modacrylic, polyacrylate, polybenzimidazole, polyester and polyoxamide, with the optimum variant of each fibre type being selected where any difference within a generic group exists. In the ideal situation, all seven would be evaluated to compare their suitability, as long as budgetary constraints would permit this approach. (There may also, of course, be some unexpected reason why any of them may not be suitable, because of high cost or low availability, for example). In an effort to eliminate candidates still further, then, it is worth ranking them by using the criteria developed earlier.

Acrylic fibres have moderate tensile strength, abrasion resistance and chemical resistance, with low absorbency and flame resistance, but are high in resilience, biological resistance and resistance to environmental (that is, for instance, light or weathering) degradation. The new cellulose has good strength, resilience and absorbency, but only moderate chemical resistance, with low biological and flame resistance. Its abrasion and environmental-resistant characteristics are not specified, but are not expected to be high. Modacrylic fibres have high values of resilience, flame resistance and biological resistance, but moderate strength, abrasion resistance, chemical resistance and environmental resistance, with low absorbency. These three should therefore be placed lower in the list of preferred types at this stage.

Of the other four, as far as can be predicted on logical grounds based on chemical

structure (since not all properties are published or investigated), all will have high values of strength, resilience, chemical resistance, biological resistance and environmental resistance. Absorbency is high for polybenzimidazole and polyoxamide, but low for polyester and polyacrylate. Flame resistance is moderate for polyester and high for the other three fibres. Thus, the only critical factor remaining is abrasion resistance and, unfortunately, there is a dearth of information for two of the fibres (polyacrylate and polyoxamide) in this area. PBI has an astonishingly high abrasion resistance (it cannot be cut with a knife, though may suffer from production difficulties as a result) and polyester's abrasion resistance is also high.

Thus, if all the properties are taken into account, with equal weight being given to them, the ranking is in the approximate order PBI, polyoxamide, polyacrylate, polyester, modacrylic, acrylic and cellulose, with high-tenacity polyamide also being a possible candidate. The decision on which fibres to investigate further for use in protection then becomes a financial one.

12. YARN AND FABRIC PRODUCTION

If an investigation of usefulness in protective clothing is carried out, a logical order should be followed. Once a decision is taken on which fibres to investigate further, all of those which are to be considered should be made up into fabrics in the most economical way possible, using identical processing conditions without regard for achieving optimum ones, so that the fibres can be subjected to intensive testing to determine their comparative performance under specified circumstances. In addition, the availability in commercial quantities should be explored more fully with manufacturers. Despite the newer techniques of production on the market, it is probable that weaving would still be preferred for fabric construction, since it gives the most durable end-product of all the manufacturing methods currently available. However, the possibility of using recently-developed coating techniques (to improve water-, chemical- or microbiological-resistance, for example) for obtaining improved protection should be considered seriously.

Once the fabrics have been obtained from the fibres selected, tests of the critical properties should be carried out. Evaluations of strength and abrasion resistance under accelerated degradative conditions, before and after subjecting the samples to ultraviolet light exposure in the Weatherometer, should be conducted in an effort to rank the fibres in order of suitability for each specific end-use activity.

Any investigation should take into account all added benefits which may arise. The question of whether a fibre imparts good moisture vapour transfer (for reduced perspiration retention in high temperatures or at intense levels of activity in the Arctic), or has good flame resistance, or a low density, or is environmentally less damaging than a competitor, for instance, may have some bearing on the decision of which fibre type to use for which task. Only then will it be possible to be sure that the optimum combination of fibre type and construction techniques for the

desired application in aircrew or support staff use has been achieved. By this means, comfort and survival prospects will both be enhanced to the maximum extent possible.

13. CONCLUSIONS

The need for protection, whether from natural or human hazards, remains paramount in military activities. Textile products, in the form of clothing, are an invaluable aid to this end, and new materials should be investigated to determine whether they are more effective than traditional ones. In extreme conditions caused by hot or cold climates, comfort aspects must also be taken into account for maintaining personnel in a state of efficient readiness, since the provision of protection without concern for comfort can lead to survival risk or hinder mobility and dexterity. From published literature, a number of fibres appear to offer substantial improvements in offering enhanced protection without sacrificing comfort unduly.

FIRE-RESISTANT WATER VAPOUR PERMEABLE BUOYANT INSULATION

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SUMMARY

Compared to closed cell foam, constant wear garments designed with this material provide added comfort due to increased heat losses during sweating, shortened drying times after sweating, and added flexibility. Although introducing water vapour permeability causes a degradation to the material's cold water immersion protection, the integrity of its fire protection and buoyancy remains unaltered.

LIST OF SYMBOLS

Q	Heat Flow ($W{\cdot}m^{-2}$)
R_t	Thermal Resistance ($m^2{\cdot}K{\cdot}W^{-1}$)
R_v	Vapour Resistance ($s{\cdot}m^{-1}$)
F_b	Buoyant Force (N)
m	Mass (kg)
t	Time (hr)
T_a	Air Temperature (C)
T_s	Plate Surface Temperature (C)
T_w	Water Temperature (C)
f	Wave Frequency (Hz)
z_{avg}	Average wave height (m)
RH	Relative Humidity (%)
TPP	Thermal Protective Performance
FR	Flame Retardant
MAC	Mustang Aviation Coverall
PVC	Polyvinylchloride

1.0 INTRODUCTION

Current constant wear aviation coveralls, insulated with closed cell foam, are worn to provide buoyancy and hypothermia protection in the case of accidental cold water immersion. These coveralls lead to thermal stress and reduced comfort when worn in hot environments or when users engage in moderate physical activity[1].

The onset of heat stress in warm environments is hastened by the excessive thermal insulation required in the advent of accidental cold water immersion. Many of these coveralls incorporate an insulating layer or shell which is impermeable to the diffusion of water vapour, hence there is no evaporation of sweat from the skin. The benefits of evaporative cooling are not utilized and moisture will accumulate in the underclothing.

The purpose of this study was to design and test a fire-resistant, water vapour permeable, buoyant and thermally insulating material for use in these garments.

1.1 Function of Proposed Material

Holes were punched through the layer of PVC foam to provide pathways for vapour diffusion and thermal radiation. These holes allow some sweat to evaporate directly at the skin since this aids in keeping the user cool and dry during periods of moderate activity with low but appreciably amounts of sweat (Figure 1).

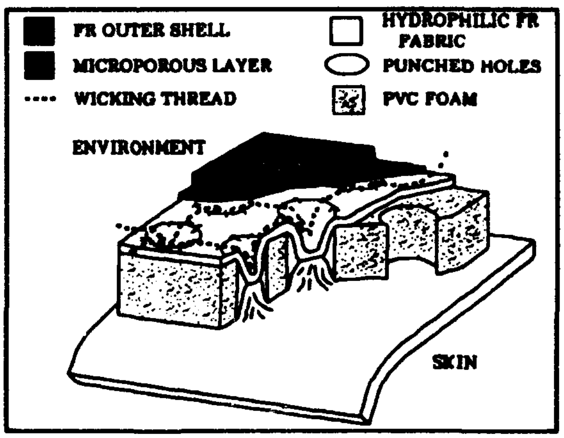


Figure 1 - Cut-away view of permeable ensemble

Hydrophilic fabrics were placed on each side of the foam. Sewing these fabrics together forms fabric and thread pathways for transporting liquid sweat through the foam. These pathways allows sweat to be rapidly absorbed from the user's skin/underclothing, wicked through the layer of closed-cell PVC foam and then thinly spread next to the outer shell for evaporation.

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

2.0 METHOD AND RESULTS

2.1 Optimization of Fabrics

To optimize this fabric ensemble required examination of the following parameters:

- size and density of the holes punched in the closed-cell PVC foam.

- wicking and drying rates of the hydrophilic FR fabrics.

- wicking rate of the thread sewn through the layer of foam.

- water vapour permeabilities of the various fabric layers.

- FR integrity.

2.1.1 Addition of Evaporative Pathways

A combination of theory[2] and sweating hot plate experiments[3] were conducted on various fabric ensembles. Initially, the ratio of punched hole area to solid foam area was varied to quantify the increase in heat loss due to the addition of evaporative and radiative pathways. To understand the mechanical effects caused by punching holes through the foam, the material's flexibility, tear strength and buoyancy were monitored.

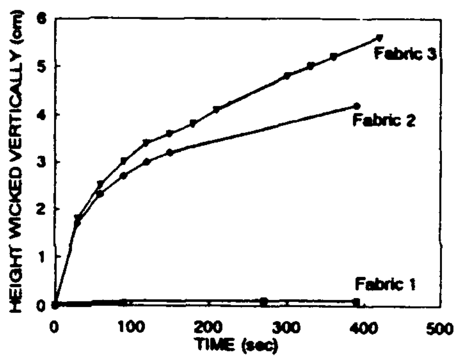
Punched holes diameters in excess of $1.1 \cdot 10^{-2}$ m were required to ensure existing manufacturing methods could achieve adequate surface contact between the two layers of hydrophilic FR fabric, within the hole site. This direct contact is essential to providing good liquid transport characteristics.

The spacing between adjacent hole centers depends upon the desired ratio of punched hole area to solid foam area. Increasing hole area has the desirable effects of increased vapour diffusion and increased flexibility, but the undesirable effects of in-water insulation loss and decreased buoyancy. No clear optimum exists; hence the ratio was arbitrarily chosen as 25% - 75%. A spacing of $2.0 \cdot 10^{-2}$ m between the centers of adjacent $1.1 \cdot 10^{-2}$m diameter holes provides this ratio. The foam thickness has to be increased by 25% to maintain a constant buoyant force per unit area of material. Decreasing the spacing between the holes to achieve a higher ratio of hole to solid foam decreases the material's breaking strength. It was observed that punching this matrix of holes doubles the foam's flexibility.

2.1.2 Wicking fabrics and threads

The vertical wicking rates of liquid water through the inner and outer FR fabrics were measured to establish which fabrics provide rapid liquid transport. Drying rates and fabric weights (dry/saturated) of these fabrics were also measured since minimum fabric weights and maximum drying rates were desirable. Water-repellent FR fabrics were examined for use as an outer shell.

FR aramid-viscose blends and FR aramids with permanent hydrophilic finishes provide higher rates of wicking and evaporation than untreated FR aramids (Figure 2 - 3). Light-weight aramid-viscose blends (119 $g \cdot m^{-2}$) were chosen as the wicking fabrics, since they do not increase the garment's overall weight significantly and provide adequate wicking characteristics. Although FR aramid fabrics exhibit a higher resistance against abrasion, FR viscose-aramid blends are cheaper and sufficiently durable[4].



Fabric 1 - Aramid (110 $g \cdot m^{-2}$ Pajama check)
Fabric 2 - Aramid w\hydrophilic finish (110 $g \cdot m^{-2}$ Pajama check)
Fabric 3 - Aramid-viscose (119 $g \cdot m^{-2}$ Pajama check)

Figure 2 - Vertical wicking of water up FR fabrics

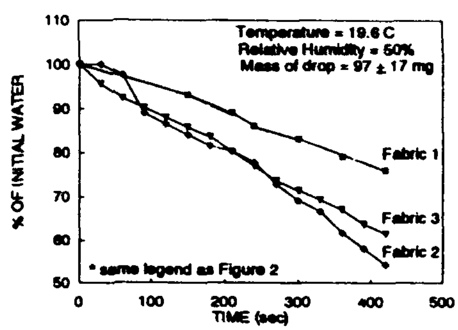


Figure 3 - Drying rates of water in FR fabrics

Threads consisting of three cotton-covered polyester yarns, twisted helically were found to wick water the highest and fastest[5]. Unfortunately, FR protection demands the use of aramid threads, hence a compromise in the wicking performance of the thread was made. A 4 x 4 cm thread grid of four stitches per centimeter was used for this material. Increasing the density of the thread grid and the number of stitches per centimeter increases liquid transport through the foam, but reduces its breaking strength and aesthetic appeal. Increased liquid transport causes more liquid to evaporate from the exterior surface; at the expense of the benefits of evaporative cooling directly at the skin surface.

2.1.3 Water vapour permeability

The resistance to water vapour diffusion was measured for a variety of microporous coated FR fabrics as a function of position away from the skin[6]. A liquid barrier that would allow for the rapid evaporation of sweat was required to reduce the in-water convective heat losses caused by turbulent water flushing through the outer shell fabric and punched holes. The selected hydrophilic microporous membrane had a vapour resistance of R_v = 28 ± 10 $s \cdot m^{-1}$ (equivalent to the diffusion across 0.7 mm of still air) when directly against a saturated surface.

The FR fabric used as an outer shell requires a permanent water-repellent finish to help prevent the absorption of external sources of liquid. No significant differences in water repellency were observed between equivalent weaves of aramid and aramid-viscose fabrics.

2.1.4 Fire-protection of materials

Since flame retardancy was considered mandatory for all the components of this material, surface burning tests[7] were conducted on all fabrics. Thermal protective performance tests[8] (TPP) were conducted on the vapour permeable ensemble and its impermeable equivalent at the University of Alberta. Tests exposed fabric swatches to Q = 83.7 $kW \cdot m^{-2}$ until the heat throughput reached that which would cause a 2nd degree burn on human tissue.

Results indicate that the vapour permeable ensemble ($8.0 \cdot 10^{-3}$m thick foam + $1.3 \cdot 10^{-3}$m fabrics) provides a TPP value of 1.72 ± 0.25 $MJ \cdot m^{-2}$ (41.09 ± 4.97 $cal \cdot cm^{-2}$), while the impermeable ($6.4 \cdot 10^{-3}$m foam + $0.7 \cdot 10^{-3}$m fabrics) provides 1.93 ± 0.08 $MJ \cdot m^{-2}$ (46.12 ± 2.01 $cal \cdot cm^{-2}$).

Since the hydrophilic fabrics used in this garment have the potential to absorb a considerable amount of sweat, it should be noted that Miller et al[9] found that moisture in fabrics can retard ignition, hence offering some added fire protection. On the other hand, when the user is exposed to high sources of external heat, this moisture may form steam inside the clothing causing tissue damage. These TPP tests were conducted on fabric swatches which were conditioned at T_a = 21.0 C and RH = 65%. Further experiments would be required to fully understand the role of clothing humidity on this material's fire protection.

2.1.5 Heat Loss

A sweating hot plate housed in an environmental chamber was used to determine the heat loss through the permeable ensemble in a warm environment (T_a = 29.0 ± 0.1 C; T_s = 35.0 ± 0.1 C; RH = 50 ± 1 %). These experiments measured the heat loss during:

- 0.5 hr prior to the onset of sweating.
- 0.5 hr of profuse sweating @ 360 $g \cdot m^{-2} \cdot hr^{-1}$.
- post-sweating (until garment was dry).

Heat loss profiles of the vapour permeable ensemble ($8.0 \cdot 10^{-3}$m thick permeable foam + $1.3 \cdot 10^{-3}$m of fabric) and its impermeable equivalent ($6.4 \cdot 10^{-3}$m thick impermeable foam + $0.7 \cdot 10^{-3}$m of fabric) are shown in Figure 4.

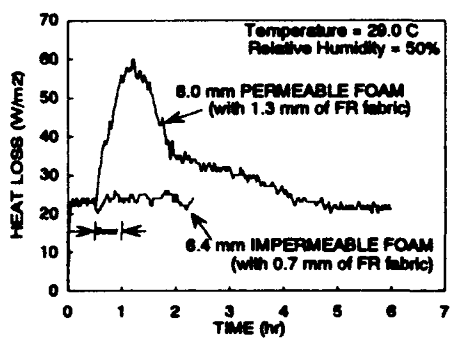


Figure 4 - Heat loss through both materials in a warm environment

These experiments show that the dry heat losses for both materials remained the same (Q ≈ 23 $W \cdot m^{-2}$)

while peak heat losses during sweating increased by 37 W·m^{-2} (+168%), for the permeable ensemble over its impermeable equivalent. This represents a thermal resistance before sweating of R_t = 0.252 m^2·K·W^{-1} (1.63 clo). Using the hot plate in conjunction with a water column, the thermal insulation was measured as a function of still water depth (Table 1).

Depth (*m*)	*Thermal Resistance* (*m^2·K·W^{-1}*)	[*clo*]
0.1	(0.074)	[0.476]
0.2	(0.059)	[0.380]
0.3	(0.044)	[0.281]
0.4	(0.035)	[0.229]
0.5	(0.029)	[0.186]

Table 1 - Still water thermal insulation of permeable ensemble

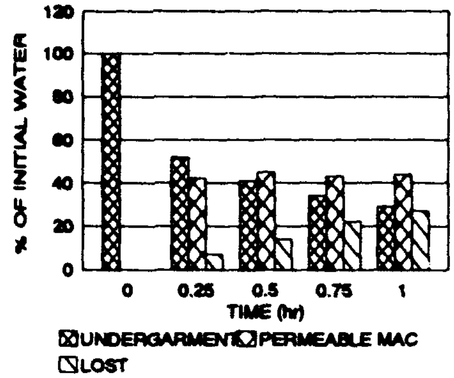


Figure 5 - Distribution of water in permeable MAC

2.2 Optimization of Garment Design

A prototype garment based on the popular constant wear Mustang Aviation Coverall (MAC) was built using the permeable fabric ensemble. The MAC is a loose fitting, "wetsuit-style" aviation coverall with Velcro® strap closures at the wrists, ankles and neck. Leg pockets contain a hood and pair of gloves made of neoprene.

2.2.1 Full coverall drying experiments

Experiments were conducted on three test subjects to compare the drying rates and perceived comfort of a MAC made with permeable foam against a MAC with impermeable foam. This experiment consisted of pre-soaking the subject's underclothing (flight suit) with water then allowing him to dry while sitting at rest (m_{H2O} = 0.769 ± 0.076 kg; t = 1 hr; T_a = 20.1 ± 1.8 C; RH = 51 ± 2%). The mass of water remaining in the underclothing, transferred to the MAC and lost through evaporation was measured at 15 minute intervals.

Trials with subjects wearing a permeable version of the MAC, show that 71.0 ± 6.0 % of the water initially introduced to the underclothing was removed after 1 hr of drying (Figure 5).

In the impermeable MAC, only 45.7 ± 2.3 % of the initial water was removed after 1 hr of drying (Figure 6). All subjects perceived increased comfort in the permeable coverall due to the enhanced removal of liquid sweat from the underclothing.

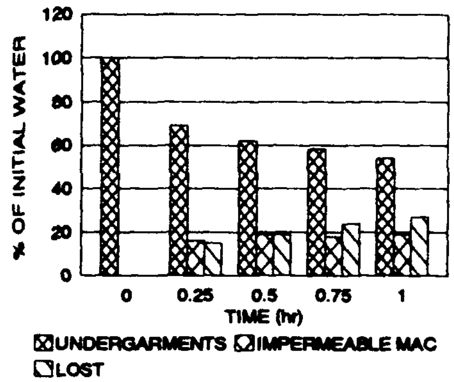


Figure 6 - Distribution of water in impermeable MAC

2.2.2 Fire Protection of Coverall

Thermal mannikin tests of the impermeable MAC were conducted by the University of Alberta's Textile Analysis Service, on their Fire Protection Evaluation System. These tests exposed the garment to a fireball of Q = 79.5 kJ·m^{-2}·s^{-1} for t = 4 s.

The nude mannikin received 2nd and 3rd degree burns to 85.60% of its body surface area; 6.45% and 79.15%, respectively (Figure 7).

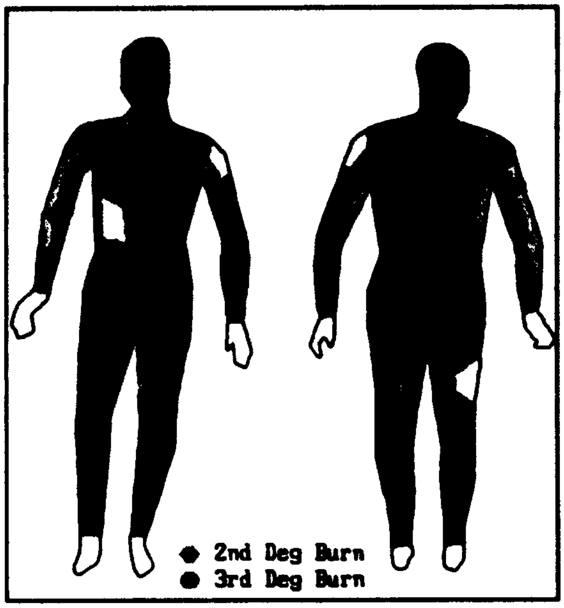


Figure 7 - Burns to nude mannikin (L:front; R:back)

For comparison, a typical aramid flight suit allowed 2^{nd} and 3^{rd} degree burns to 64.15% of the body surface area; 56.50% and 7.65% respectively (Figure 8).

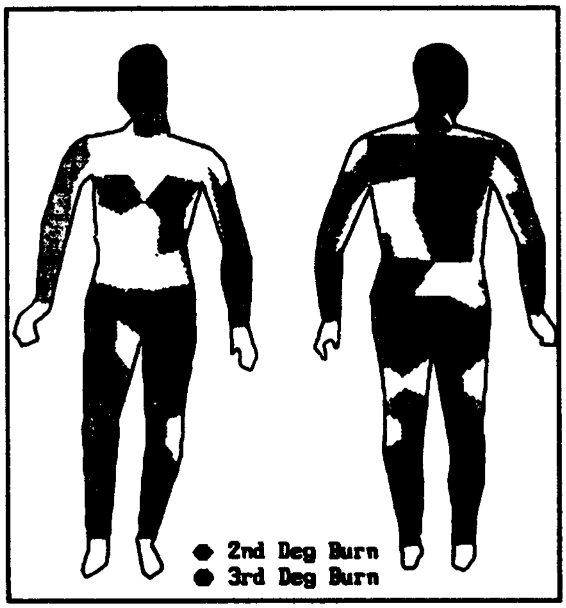


Figure 8 - Burns through a flight suit

The impermeable MAC offered substantial protection against skin burns. Only 7.65% of the body surface area received 2^{nd} and 3^{rd} degree burns; 0.65% and 7.0%, respectively. These burns occurred predominately in the head and neck regions where no protection was expected (Figure 9).

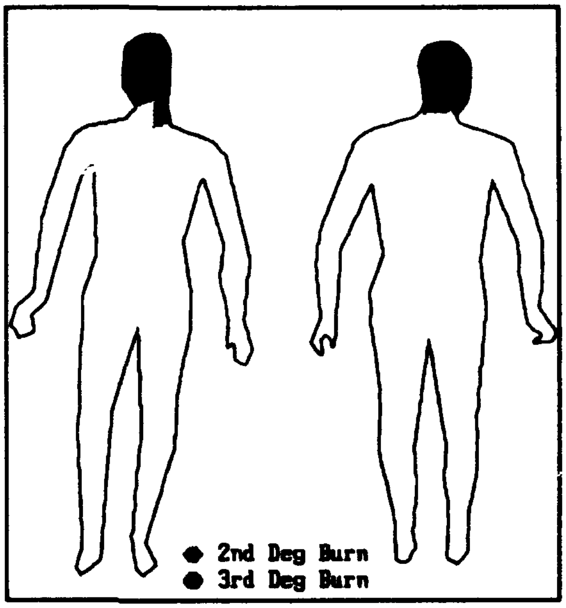


Figure 9 - Burns through an impermeable MAC

Full mannikin flame exposure tests were not conducted on the vapour permeable MAC, since both materials had similar TPP values, it was assumed the results from the mannikin would also be similar.

2.2.3 In-water thermal insulation of coverall

The thermal insulation[10] in turbulent water of both coveralls were measured on a heated mannikin by the Cord Group. Tests of three variations to the permeable MACs were conducted; the permeable ensemble without a microporous liquid barrier, with the barrier and finally, with the addition of leg straps and better wrist closures. The thermal resistances of each individual garment section are compared in Table 2.

The average thermal resistances (in turbulent water) of each variation of permeable MAC (T_w = 16.2 ± 0.2 C; avg. wave height = 0.305 m, 2.3 sec apart) were found to be R_t = 0.0211, 0.0229 and 0.0242 $m^2K{\cdot}W^{-1}$ (0.1363, 0.1477 and 0.1555 clo) respectively, compared with 0.0405 $m^2K{\cdot}W^{-1}$ (0.2606 clo) for the impermeable suit.

Body Section	*Permeable MAC (clo)*			*Imp. MAC*
	(no barrier)	*(with barrier)*	*(with straps)*	*(clo)*
R. Arm	0.0628	0.1402*	0.1236	0.2597
L. Arm	0.0796	0.1833*	0.1204	0.1429
R. Leg	0.1321	0.1492	0.1855*	0.4111
L. Leg	0.1767*	0.1448	0.1729	0.3460
Abdomen	0.1041	0.1834*	0.1372	0.3767
Buttocks	0.2467	0.3103	0.5328*	0.5846
Chest	0.0829*	0.0520	0.0612	0.1279
Back	0.1928*	0.1809	0.1402	0.4717
R. Hand**		0.3891 ± 0.0723		
L. Hand**		0.4086 ± 0.0344		
R. Foot**		0.1552 ± 0.0323		
L. Foot**		0.1872 ± 0.0247		
Head**		0.5734 ± 0.0763		
SUIT AVG:	0.1363	0.1477	0.1555	0.2606

* - *denotes highest insulation value of permeable MAC*
** - *neoprene gloves, neoprene hood and flight boots*

Table 2 - Thermal resistances of permeable and impermeable MAC in turbulent water

This loss of average suit insulation (-47.7, -43.3 and -40.2 %) is due to the introduction of holes in the foam as well as an increase in the amount of water flushing through the garment's chest region and neck closure. The increased flexibility of the punched foam allows greater "pumping" action within the suit when in turbulent water. The microporous barrier enhanced the overall thermal resistance of the suit, but seems to have decreased the insulation of the chest and abdomen regions. The addition of straps at the legs increased the insulation on the legs. It is possible that the reduction of flushing in the legs decreased the exchange of warm water from the legs through to the chest. Tightening the legs straps also decreased the trapped airspace above the chest.

2.2.4 Buoyancy

Since this coverall is designed primarily for use by helicopter crews, its buoyancy was measured to ensure it would not hinder egress from a submerged helicopter.

The total buoyancy supplied by the permeable and impermeable MAC were F_b = 73.9 N (16.6 lbs) and 91.6 N (20.7 lbs), respectively. This loss of suit buoyancy, (-19.8%) is due to punctures and compression caused from sewing through the foam, as well as the increased weight of the coverall (2.55 -> 3.38 kg) due to the additional layers of fabric.

Although the suits supply less than a recommended maximum escape buoyancy[11] of 156 N (35 lbs), they were not measured using actual subjects hence the additional buoyancy supplied by trapped air is not included.

It was noted that the impermeable suit takes more time to vent its trapped air than the permeable suit. Upon removing the suits from the water, the permeable suit takes longer to drain water than the impermeable suit. This is due to the increased absorption of water in the fabric layers and trapping of water in the holes.

2.3 Alternative applications for permeable foam

This material makes a good replacement for fleece and fibrous batting insulating garments worn by aviators underneath constant wear vapour permeable dry suits. Since PVC foam is not as succeptible to hydrostatic compression as are battings, less uncompressed thickness of permeable foam is required to achieve the same in-water insulation as batting (Figure 10).

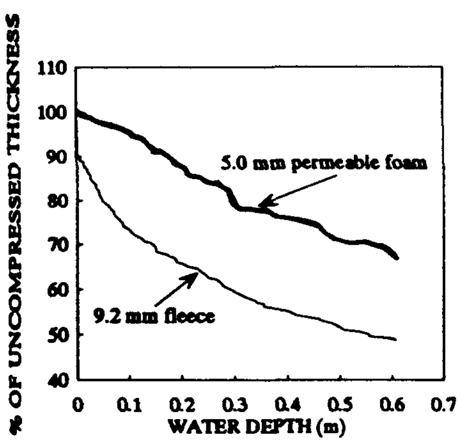


Figure 10 - Thickness of fleece and permeable foam vs submerged depth

To achieve a thermal resistance of R_t = 0.124 $m^2 \cdot K \cdot W^{-1}$ (0.8 clo) from both materials under 0.5 m of water, 5.0 mm of permeable foam and 9.2 mm of fleece were required underneath a vapour permeable FR shell.

When these insulations are uncompressed, the batting is thicker than the foam. As expected, sweating hot plate experiments in a warm environment show that vapour permeable foam allows for greater dry heat losses than fleece (T_a = 29.0 ± 0.1 C; RH = 30.0 ± 1.0%; sweat rate = 360 $g \cdot m^{-2} \cdot hr^{-1}$).

Typically, a batting has a lower resistance to water vapour diffusion than the permeable foam, hence its higher heat losses during sweating and shorter post-sweat drying time. This drying time is indicated by the heat loss returning to its original pre-sweat value (Figure 11).

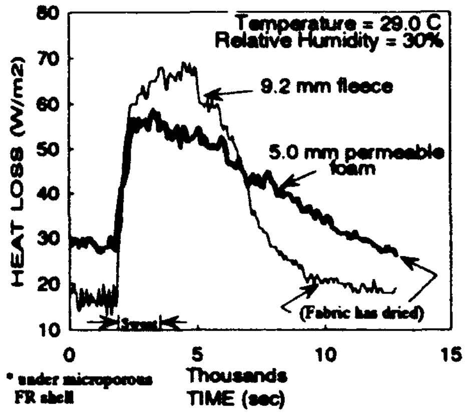


Figure 11 - Heat loss through dry suit in warm environment

Tests simulating 0.5 hr of water leakage into the insulation underneath a submerged Nomex-Gore-tex® dry suit shell (T_w = 21.0 ± 0.5 C; leak rate = 360 $g \cdot m^{-2} \cdot hr^{-1}$; d = 0.5 m), found permeable foam retains a greater amount of its thermal insulation. The partial vapour barrier formed by the foam reduces the evaporative heat losses through the permeable foam in comparison with the fleece. However, upon stoppage of the leak, fleece was found to dry faster than the foam (Figure 12).

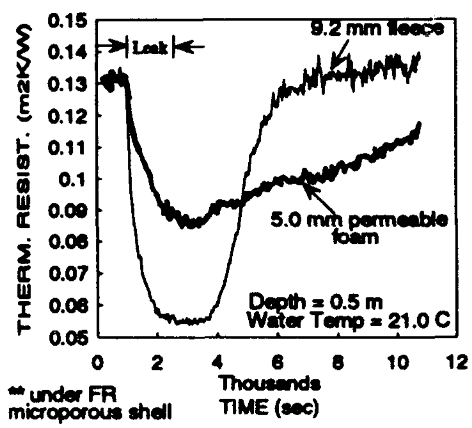


Figure 12 - Leakage of water into a dry suit

Closed-cell foams possess inherent buoyancy which is not lost in the event of leakage into the dry suit. The shock absorbing capabilities of closed-cell foam may also offer a degree of protection against injuries due to striking blunt objects.

3.0 CONCLUSIONS

This permeable material offers greater heat losses during and after sweating than its impermeable equivalent. The comfort of a constant wear aviation coverall was improved due to enhanced liquid management and additional flexibility. This material provides ample buoyancy and moderate hypothermia protection during cold water immersion, and exhibits excellent FR protection.

Enchancing the thermal protection offered from a "wetsuit- style" garment using this material may be achieved by improving the integrity of the closures.

Further studies are required to determine the benefits of replacing current insulating battings underneath vapour permeable dry suits with this material.

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5.0 ACKNOWLEDGEMENTS

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DEVELOPMENT OF A NEW CHEMICAL WARFARE AGENT PROTECTIVE MATERIAL

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INTRODUCTION

In 1976 W. L. Gore & Associates, Inc. invented GORE-TEX® fabric utilizing expanded polytetra-fluoroethylene (ePTFE). This was the first truly waterproof and moisture vapor permeable fabric laminate. In 1980 the company began to develop products for military applications. Since that time, Gore has supplied GORE-TEX fabric for, and assisted in the development of, some of the military's most technically sophisticated apparel: the U. S. Army's Extended Cold Weather Clothing System (ECWCS), the U. S. Navy's Over Water Flight Suit (OWFS), and the U. S. Air Force's Security Police Jacket being but a few examples. All of these garments provide the user with increased levels of protection from harsh environments and have proved themselves to be very durable. GORE-TEX fabric laminate has consistently proven itself to be technically superior to any other material.

This paper details the development by Gore of a new chemical warfare protective material based on proven ePTFE technology combined with a new highly activated polymer system (APS).

HISTORICAL PERSPECTIVE

Since World War I the number of Chemical and Biological (C/B) agents that may be used on the battlefield has increased dramatically. As the number and types of agents has increased (U. S. Army FM 3-5 list twenty-nine different agents), the job of the clothing and equipment designers has become ever more complicated. State of the art C/B protective clothing has been designed to counter vapor threats with some degree of success. But, there is disagreement on how well these items will protect an individual from agents in liquid and aerosol form, in addition to the other contaminates that can be encountered on the battlefield.

The military publications used to train operational forces address the issue of C/B gear limitations, but only in a relatively broad sense. Consider the following from FM 3-5:

"Although MOPP gear will provide protection from most chemical and biological agent attacks, several limitations will begin to reduce its effectiveness. Some concentrations of contamination may eventually overcome the gear's protective qualities. Agents can gradually penetrate the mask hood. The charcoal in the mask filters and the overgarments eventually may become saturated. **Water, fuel, grease, or oil could defeat the protection qualities of the MOPP gear.**[1]"

This quote is interesting, for what it does not tell the individual is that the only thing protecting his clothing from the "water, fuel, grease, or oil" is a water-repellent fabric finish. Even the best of these finishes, which rely on lowering the surface energy of the fabric, have very limited durability when compared to liquid impermeable/vapor permeable (LI/VP) fabric laminates. In addition, this type of finish can be wetted if foreign particles are present, and

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it is highly susceptible to penetration from pressure (a person sitting on a contaminated surface can defeat the finish) or saturation (a person assuming a prone position in a puddle of water or mud will overwhelm the finish). All of these situations would be common in a combat or work environment. In contrast, a properly designed LI/VP fabric laminate does not rely on the fabric finish to provide liquid protection, but rather relies on a semipermeable membrane to achieve this characteristic.

GARMENT DESIGN LIMITATIONS IMPOSED BY CONVENTIONAL TECHNOLOGY

The challenge faced by the developers of protective clothing is to design a functional uniform that will provide absolutely reliable protection without imposing an unacceptable level of heat stress. This has posed a significant problem since combining these two qualities in one layer has proven very difficult. Generally, the approach has been to use either relatively thick carbon loaded materials, such as the carbon impregnated foam used in the U. S. OG84, or to use thin material in conjunction with other layers of clothing to achieve an acceptable level of aerosol and liquid agent protection. The Aircrew Uniform Integrated Battlefield (AUIB) employs the latter technique by using a GORE-TEX fabric outer material and an attached carbon loaded lining. Both of these approaches suffer from the same limitation; as the protective material becomes thicker, or as more layers are added, the insulation value of the uniform and its resistance to evaporative heat loss is increased, thus, imposing additional heat stress on the user.

An alternative approach is to design the protective clothing system in two independent garments with vapor protection in an adsorptive layer and liquid/aerosol agent protection in a separate LI/VP layer. In such a system the vapor agent protective layer is always worn, providing protection from the majority of the threat while imposing minimal heat stress. The liquid/aerosol protection layer is worn only when there is a liquid/aerosol agent threat, or to provide protection from climatic extremes. The virtue of this approach is that the person only wears the full system when the threat is the highest, thus limiting the time he is exposed to the maximum potential heat stress. A system such as this could work well in conjunction with the U. S. military's Extended Cold Weather Clothing System (ECWCS) if the adsorptive layer is designed to function as an integral component of the cold weather clothing. Unfortunately, this "layered protection" approach has not met with general acceptance in the user community where the focus has remained on obtaining systems with all of the protection built into one layer. It is, however, a viable option in situations where the threat of exposure to liquid and/or wind driven agents is low.

It is recognized that increasing the level of protection entails a corresponding decrease in the ability of the individual to perform his mission.[2] In the U. S. military the Mission Oriented Protective Posture (MOPP) is used to provide the operational commander with a flexible response to a C/B threat. However, once forced to assume the highest MOPP level the degradation in performance is significant even under the best circumstances.

Since 1984 W. L. Gore & Associates, Inc. has explored the use of conventional GORE-TEX fabric for use in chemical/biological (C/B) warfare applications, resulting in several new uniform concepts, such as the U. S. Army's AUIB, mentioned above. In 1990 Gore launched a project to develop an industrial and military protective material that would alleviate many of the problems associated with traditional protective apparel concepts. The objective of the project was to invent a material that could be incorporated into the normal clothing and equipment items used by the individual and have minimum adverse impact on job or mission performance when operating at the highest protection level. To accomplish this the material had to come as close as possible to the physiological performance of the material that the person normally wears while providing absolutely reliable chemical and biological agent protection. As a result of this research, new laminates have been devel-

oped that offer the C/B clothing and equipment developer significantly more latitude in designing new items.

PHYSIOLOGICAL PERFORMANCE OF CHEMPAK™ LAMINATE GARMENTS

Garments constructed of W. L. Gore & Associates, Inc. new ChemPak™ laminate and ChemPak™ LT laminate provide an extraordinary degree of chemical and biological warfare agent protection while reducing the physiological burden normally associated with protective apparel. ChemPak™ products achieve this performance by combining the properties of several unique materials: ePTFE, carbon adsorbent, and a highly activated polymer system (see Fig. 1a and 1b). The combination of these products results in a material laminate that is effective against known classes of chemical warfare agents while being much less dependent on carbon adsorptive technologies than traditional approaches.

The use of LI/VP materials may also offer increased capabilities when operating in an area of biological contamination. The nature of the material may make it much easier to decontaminate a uniform by using wash down techniques such as showers after exposure to biological agents.

The development of the activated polymer system by a Gore science and engineering team has provided us with the capability to significantly alter the way that the U. S. serviceman dresses for combat. Due to this polymer's unmatched characteristics, an exceptionally high moisture vapor permeation rate coupled with unequaled resistance to penetration by chemical warfare agents, **Gore has been able to simultaneously increase chemical protection while reducing physiological stress on the individual.**

Gore has developed two variations of its C/B protective material. ChemPak™ laminate combines ePTFE, activated carbon, and the polymer composite. structure. ChemPak™ LT laminate consists of only ePTFE and the APS. Due to their unique characteristics, ChemPak™ laminate and ChemPak™ LT laminates have the potential to alleviate many of the problems posed by the current generation of C/B ensembles. Traditional approaches have relied on air permeability to alleviate heat stress but the prospect of such systems becomes limited since thickness or layers have to be increased to maintain C/B protection. Figure 2 illustrates some of the possible protective clothing configurations.

Fig. 1a

CONSTRUCTION OF CHEMPAK™ LAMINATE

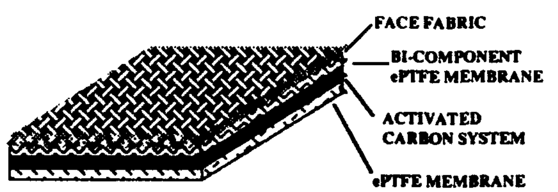
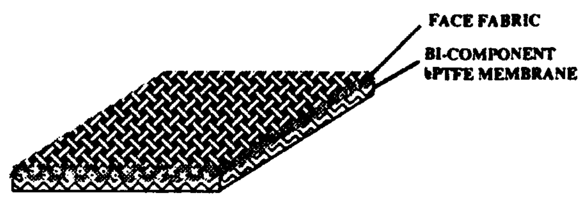


Fig. 1b

CONSTRUCTION OF CHEMPAK™ LT LAMINATE



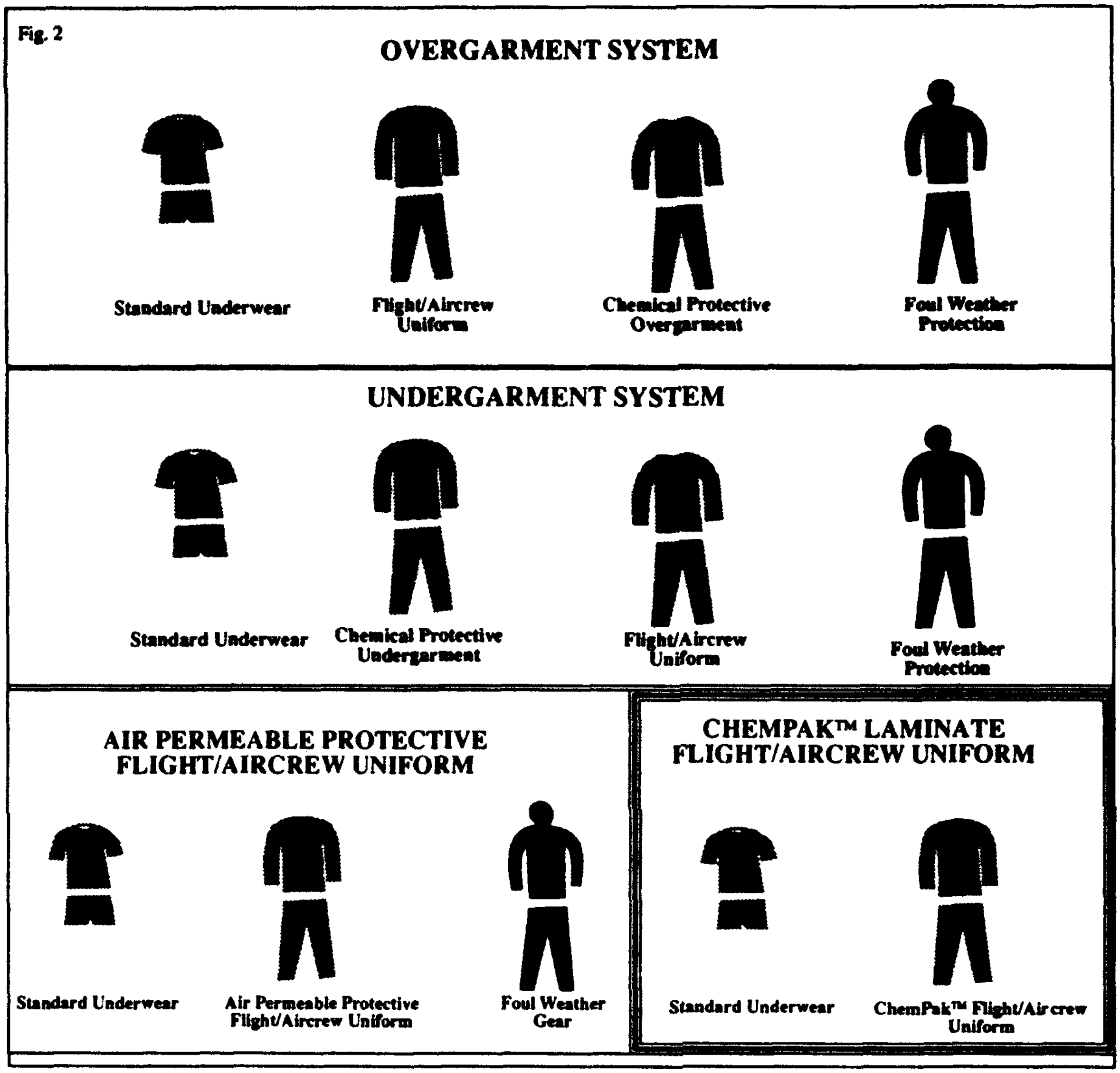


Fig. 2

It has been assumed that the use of air impermeable materials, such as the ChemPak™ laminates, would not offer an improvement over the current situation. However, this assumption was predicated on the use of the LI/VP fabric in multiple layers or in a single layer having a very high resistance to evaporative heat loss. Recent human subject testing has indicated that a protective uniform constructed of ChemPak™ laminate, with its exceptionally low resistance to evaporative heat loss, and employed as a primary use garment, can offer reduced heat stress while increasing C/B protection.

Physiological studies were conducted at Pennsylvania State University on four chemical protective ensembles in an attempt to determine the maximum environmental conditions (ambient temperature and humidity) in which a person can maintain a fairly constant body core temperature while wearing these garments, the M-40 respirator, and protective butyl rubber gloves.[3] The test methodology uses volunteer subjects walking continuously on motor-driven treadmills in a computer-controlled environmental chamber for up to 2.5 hours. The work intensity was targeted at

an energy expenditure of 5 kcal/min. or approximately 30% of each subject's maximal aerobic capacity (VO_{2max}). This study demonstrated that a ChemPak™ laminate clothing ensemble compares very favorably with state-of-the-art air permeable garments and is clearly superior to many technologies currently in use.

Fig. 3 illustrates the results of the physiological evaluation. The increase in performance of the ChemPak™ laminate garment relative to the standard U. S. BDO is indicated by the enlargement of the shaded area. ChemPak™ LT laminate has demonstrated lab test performance equal to ChemPak™ laminate in its ability to resist penetration by chemical warfare agents while exhibiting a reduced resistance to the transmission of moisture vapor. Physiological testing of ChemPak™ LT laminate garments is planned for the near future.

These values should not be interpreted as absolute limits, and in fact pushing the environmental conditions to the extremes, increasing the work rate, or placing an additional load on the subjects in the form of other combat equipment, will further compromise all of the systems.

If one accepts that properly designed and configured ChemPak™ laminate garments may be equal to air permeable garments in the critical area of heat stress, the next question is how ChemPak™ laminate garments perform in protecting the individual from chemical agents.

Fig. 3a

CRITICAL TEMPERATURE AT APPROX. 30 % R.H.

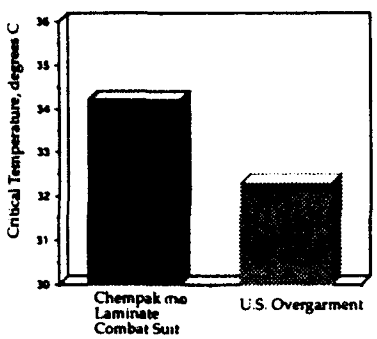


Fig. 3b

CRITICAL VAPOR PRESSURE AT 28 DEGREES C

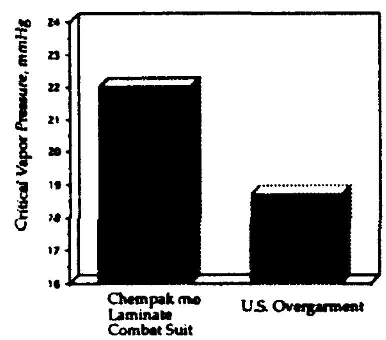
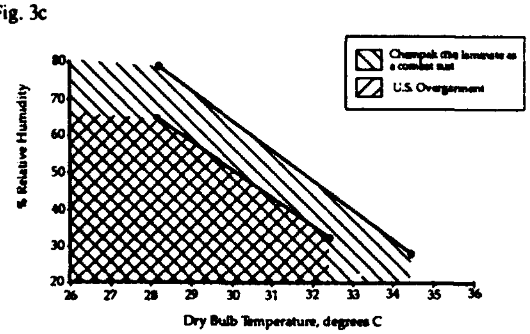


Fig. 3c



ENVIRONMENTAL LIMITS FOR CONTINUOUS WORK

Fig. 3d

PHYSICAL PROPERTIES OF GORE™ NBC LAMINATES

FABRIC LAMINATE	NAP 290 ChemPak™ Laminate	NAP 290 ChemPak™ LT Laminate
MDM DRY-KACE	9300	17400
MVTR-B	791	819

CHEMICAL PROTECTIVE PERFORMANCE OF CHEMPAK™ LAMINATE GARMENTS

Gore began its C/B material development efforts using ePTFE and spherical carbon adsorbers in what was termed "Monopack Laminate" that did not contain the activated polymer. After the discovery of the activated polymer composite structure, which was designed APS, we continued to use carbon in combination with the polymer and ePTFE in the ChemPak™ laminate but eventually determined that the APS alone might provide adequate protection in some end uses. This lead to the development of ChemPak™ LT laminate. Fig. 4 provides an overview of chemical agent testing on the early NBC laminates.

During the development of the ChemPak™ laminates, Gore identified several material tests that would provide a high level of confidence in the material's ability to perform satisfactorily under operational conditions. The focus of these tests was on product performance attributes such as chemical agent protection after laundering, after flexing at high and low temperatures, after exposure to human sweat, after exposure to battlefield contaminates such as POL's and after physical damage to the material. Fig. 5a and 5b show test results of test performed on ChemPak™ laminate.

Fig. 4

CHEMICAL AGENT PERFORMANCE OF EARLY NBC LAMINATES

FABRIC	LAMINATE	CHALLENGE	AGENT	TEST	CUMULATIVE PENETRATION microgms/sq cm (over 24 hours)	TEST DATE
US 101	Monopack Laminate	NEW	HD	LAC/VP	26.17	29-Jan-92
US 101	Monopack Laminate	NEW	tGD	LAC/VP	6.588	29-Jan-92
US 101	NBC Membrane #1	NEW	HD	LAC/VP	129.77	3-Mar-92
US 101	ChemPak™ Laminate	NEW	HD	LAC/VP	0.09	10-Mar-92

Fig.5a

CHEMICAL AGENT PERFORMANCE OF CHEMPAK™ LAMINATE AFTER LAB TESTING

FABRIC	LAMINATE	AFTER CHALLENGE	AGENT	TEST	CUMULATIVE PENETRATION microgms/sq cm (over 24 hours)	TEST DATE
US 101	ChemPak™ Laminate	FLEXED 80K CY (70F)	HD	LAC/VP	0.00	28-Aug-92
US 101	ChemPak™ Laminate	FLEXED 40K CY (-25F)	HD	LAC/VP	0.00	28-Aug-92
US 101	ChemPak™ Laminate	FLEX 1.5K CY (20% r.H.)	HD	LAC/VP	0.00	19-Mar-92
US 101	ChemPak™ Laminate	F34 JET FUEL	H	LAID DROF	0.00	31-Aug-92
US 101	ChemPak™ Laminate	Diesel Oil	H	LAID DROF	0.59	31-Aug-92

Fig.5b

CHEMICAL AGENT PERFORMANCE OF CHEMPAK™ LAMINATE AFTER ACTUAL USE AND LAUNDERING

FABRIC	LAMINATE	AFTER CHALLENGE	AGENT	TEST	CUMULATIVE PENETRATION microgms/sq cm (over 24 hours)	TEST DATE
US 101	ChemPak™ Laminate	20 HOURS OF WEAR	HD	LAC/VP	0.00	25-Jun-92
US 101	ChemPak™ Laminate	20HRS WEAR + 5 MOBILE	HD	LAC/VP	0.00	25-Jun-92
US 101	ChemPak™ Laminate	20HRS + 1 HOME LAUND	HD	LAC/VP	0.00	25-Jun-92
US 101	ChemPak™ Laminate	5 ISO WASH CYLES	H	LAID DROF	2.56	31-Aug-92

Recent testing of ChemPak™ LT laminate indicates that the APS and ePTFE used without carbon adsorbers may offer excellent protection in some applications. The data presented in Fig. 6 indicates that the protection afforded by ChemPak™ LT laminate when new is superior to that offered by many materials using carbon. Since no adsorbers are used in this configuration, Gore was concerned with how the material would perform after use and particularly after damage. Fig. 7 illustrates that damaged ChemPak™ LT laminate repaired with a patch made of similar material provides protection equal to that offered by a non-damaged area. In addition, small pin holes allowed levels of agent penetration far below guideline breakthrough concentration. Gore has used two independent test facilities and several test methods to assess the performance of ChemPak™ laminates under various conditions. Fig. 8 provides results of several of these evaluations.

Fig. 6 **CHEMICAL AGENT PERFORMANCE OF CHEMPAK™ LT LAMINATE AFTER LAB TESTING**

FABRIC	LAMINATE	AFTER CHALLENGE	AGENT	TEST	CUMULATIVE PENETRATION microgms/sq cm (over 24 hours)	TEST DATE
NAP 290	ChemPak™ LT Laminate	NEW	HD	LAC/VP	0.00	2-Feb-93
Taffeta	ChemPak™ LT Laminate	Flexed 1K Cy. @ -25F	HD	LAC/VP	0.00	12-Nov-92
Taffeta	ChemPak™ LT Laminate	Flexed 1K Cy. @ -25F	VX	LAC/VP	0.00	30-Nov-92
NAP 290	ChemPak™ LT Laminate	Syn. Sweat (Plate)	HD	LAC/VP	1.35	2-Feb-93
NAP 290	ChemPak™ LT Laminate	Syn. Sweat (Evap)	HD	LAC/VP	2.48	2-Mar-93
NAP 290	ChemPak™ LT Laminate	Flexed 80K Cy. @ 72F	HD	LAC/VP	0.00	2-Feb-93
NAP 290	ChemPak™ LT Laminate	Aircraft Fluids	HD	LAC/VP	0.00	2-Mar-93

Fig. 7 **CHEMICAL AGENT PERFORMANCE OF NBC LAMINATES AFTER DAMAGE**

FABRIC	LAMINATE	AFTER CHALLENGE	AGENT	TEST	CUMULATIVE PENETRATION microgms/sq cm (over 24 hours)	TEST DATE
NAP 290	ChemPak™ LT Laminate	With Pin Hole	HD	LAC/VP	0.81	2-Feb-93
NAP 290	ChemPak™ LT Laminate	With Pin Hole	HD	VAC/VP	0.00	2-Feb-93
NAP 290	ChemPak™ LT Laminate	Ripped	HD	LAC/VP	122.34	2-Feb-93
NAP 290	ChemPak™ LT Laminate	Rip with Gore-Tex• fabric Patch	HD	LAC/VP	11.10	2-Feb-93
NAP 290	ChemPak™ LT Laminate	Rip with NBC Patch	HD	LAC/VP	0.00	2-Feb-93
NAP 290	ChemPak™ LT Laminate	.25" Hole with NBC Patch	HD	LAC/VP	0.00	2-Feb-93
NAP 290	ChemPak™ LT Laminate	.25" hole w/ Gore-Tex• fabric Patch	HD	VAC/VP	1.23	2-Feb-93
US 101	ChemPak™ Laminate	With Pin Hole	HD	LAC/VP	0.00	2-Feb-93
US 101	ChemPak™ Laminate	With Pin Hole	HD	VAC/VP	0.00	2-Feb-93

Fig.8 **CHEMICAL AGENT PERFORMANCE OF GORE™ NBC LAMINATES USING DIFFERENT TEST METHODS**

FABRIC	LAMINATE	AFTER CHALLENGE	AGENT	TEST	CUMULATIVE PENETRATION microgms/sq cm (over 24 hours)	TEST DATE
US 101	ChemPak™ Laminate	NONE	H	Finabel Vapor	0.00	31-Aug-92
US 101	ChemPak™ Laminate	NONE	50 MicroL H	2kg/sqcm Pressure	0.36	31-Aug-92
US 101	ChemPak™ Laminate	NONE	GD	2kg/sqcm Pressure	0.00	31-Aug-92
US 101	ChemPak™ Laminate	NONE	4 microl tH	Falling Drop 7m	0.45	31-Aug-92
NONE	NBC Membrane #3	Γ Sample Tested 5x	HD	LAC/VP	0.00	6-Jan-93

In addition to the laboratory testing shown above, Gore has recently concluded a field durability test of the two ChemPak™ laminates. The test was designed as a "worst case" trial of the materials, exposing the protective characteristics of the laminates to direct daily wear and tear. Data from this test is currently being analyzed, but initial impressions are that durability of the chemical protection afforded by the materials under hard field wear conditions is acceptable.

CONCLUSIONS

In stating the benefits of ChemPak™ laminate in chemical protective clothing and equipment, we must look to the future, and this ; well beyond the recent conflict with Iraq. It is very likely that C/B weapons will become the weapons of choice for third world countries wishing to challenge the U. S. These weapons are the underdeveloped nation's nuclear weapons, and they will not hesitate to use them against our forces. The implications of this are that the ability to operate effectively in a C/B warfare environment, will become much more critical. This type of operation must become the norm rather than the exception for all U. S. forces, and this means routine operations conducted at an increased level of MOPP. But, as discussed earlier, the higher the MOPP level the greater the degradation in performance. The impact of C/B gear on performance will have to be reduced while maintaining, or even increasing, the level of protection. This can be accomplished by designing primary use garments using ChemPak™ laminate.

This approach has a number of benefits to the operational commander. The individual will always have some level of protection while wearing his standard work uniform; the number of layers the individual must wear at the highest MOPP level is reduced, thus reducing heat stress; the person's load is reduced - he no longer carries clothing just for the C/B threat, his garments are multi-functional; the serviceman is protected from aerosols and particulates, as well as environmental hazards; and, his garments will remain functional under conditions where the old items would have failed, i.e. when exposed to water, grease, or oil. The value of ChemPak™ laminate is that it is the only material which does not require the developer to utilize air permeability as the primary mechanism for reducing heat stress at the highest MOPP level. In addition, these garments do not add to the load the individual must carry since they can be designed as a primary use garment. LI/VP material in the form of the GORE-TEX fabric Extended Cold Weather Clothing System (ECWCS) has a proven record of military performance over the last ten years. By combining inovative technology with proven ePTFE performance, Gore has invented a material with exceptionally high value for military users:

- Provides complete protection against both liquid and vapor chemic l threats including wind driven vapor and liquid under pressure.
- Materials cannot be compromised by POL's, water, and other liquids.
- Provides an excellent barrier against aerosols, fine particulates, and contaminated sand.
- Material can be seam sealed to provide comparable performance of the seams.
- All of the above can be achieved without increasing physiological load.

ChemPak™ laminate garments are currently being evaluated by the U. S. Army, U. S. Marines, U. S. Air Force, and the U. K. Ministry of Defense.

REFERENCES

[1]U. S. Army FM 3-5, NBC Decontamination, 1985, Chapter 2, pg. 2-2.

[2]Field studies such as the Combined Arms in a Nuclear and Chemical Environment (CANE) have demonstrated reductions in the soldier's combat effectiveness of up to 50%.

[3]Kenny, W. L. and Puhl, Susan M., "Critical Environmental Conditions and Heat Exchange Coefficients for 4 Chemical Protective Suits", The Pennsylvania State University, 1992.

[4]Ibid., pg. 15

THERMAL PROTECTIVE PERFORMANCE AND INSTRUMENTED MANNEQUIN EVALUATION OF MULTI-LAYER GARMENT SYSTEMS

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SUMMARY

The purpose of this research was to evaluate the relative effectiveness of different clothing systems in their contribution to protection against exposure to high heat flux flash fires. All systems were exposed to controlled simulated flash fires (80 or 84 kW/m^2) on a thermally instrumented mannequin. The percentage of the mannequin surface reaching 2nd and 3rd degree burn criteria was recorded. In addition, the multiple layers of fabrics which were used together in each of the garment systems were tested according to a standard thermal protective performance (TPP) test.

The protection provided by multiple layered garment systems was significantly greater than would be expected from the additive effects of the layers used singly. The outer layer of a garment system must be flame-retardant, however; wearing a flammable garment over a flame-retardant one clearly negates the benefits of the FR layer. While it cannot be concluded for certain that undergarments must also be flame-retardant, results demonstrate that FR undergarments offer more protection than non-FR ones, especially when worn under the relatively light-weight fabrics which may be used for military flightsuits.

Only in one experiment with garment systems comprising all-FR layers did small-scale TPP tests indicate the relative protection provided by the systems. The TPP test did not indicate the potential hazard of systems in which the outer layer is non-FR. Nor did it differentiate among the three different flightsuit fabrics or demonstrate the relative protective performance of different underwear materials.

1. INTRODUCTION

In many military and industrial settings, exposure to flash fires, fireballs or pool fires is a potential hazard. Ignition of gas leaks in the oil, gas, and petrochemical industries and fire associated with aircraft accidents result in injury and loss of life through skin burns.

Investigations of industrial accidents suggest that workers can be exposed to intense heat flux (80kW/m^2) for short periods of time, typically five seconds or less. Most fires that air crew will have to contend with are a result of crashes which involve burning fuel. The task of defining the threat/hazard of a postcrash fire is difficult, partly due to the random nature of the many variables - wind speed, wind direction, nature and extent of fuel spread and/or spray, terrain topology, nature of soil and/or foliage in the vicinity of the fire, etc. (1). Conn and Grant (2) noted that estimates of thermal hazards have been made in the literature, but few are very definitive. In the case of fuel fire thermal hazards, a heat flux of 84 kW/m^2 (2.0 cal/cm^2·s) was reported to correspond to conditions around a crashed aircraft when fuel is burning fiercely; other researchers have suggested heat fluxes from 0.5 to 3.5 cal/cm^2·s. Knox, Wachtel, & McCahan (3) reported that a JP-4 fuel fire (helicopter fuel) reaches maximum intensity and 'steady state' thermal dynamics 20 s after ignition, and to have a reasonable chance of survival the aviator must get out of the fireball within 10 s. They stated that studies have led to a definition of the worst credible thermal environment as 5.5 cal/cm^2·s.

Protection from the effects of fire exposure requires clothing that does not melt, ignite, shrink, or disintegrate upon exposure, and clothing with sufficient insulating values that for the time of exposure, the amount of heat transferred through the clothing is not sufficient to raise skin temperature to levels which will cause serious burn damage (second and third degree burns). To meet the first condition, fibers which are inherently flame resistant or fabrics which have been given a chemical treatment which makes them flame retardant are used; these are often grouped together under the term FR fibers or fabrics. The FR fibers/fabrics which are commercially available for thermal protective clothing do not burn in the conventional sense (they are not ignited by holding a match to them in normal room conditions); however, if there is sufficient air flow or if temperature or heat flux is high enough, most can be made to burn, and melting, shrinking and disintegration upon exposure are common at higher exposures.

The insulating value of protective clothing is an equally important consideration. The transfer of heat through the fabric layers is a complex combination of the effects of conduction and radiation heat transfer. In a gross sense, fabric weight is one of the most important single variables determining insulation of single layers, subject to the influences of thickness and porosity. Increasing fabric weight for a particular fiber has been shown to reduce the extent of skin burning; however, some materials are more effective than others, so that a general correlation of this form does not hold (4). A layered clothing system with air spaces should give more protection than a single layer. Adding layers of protective fabric increases the insulating effect which reduces the maximum temperature reached by the skin. This also reduces the instantaneous heat flux and total energy transferred to the skin.

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Evaluation of protective clothing for use in potentially hazardous environments has typically been through small scale laboratory tests of flame resistance and thermal protective performance (TPP). Small scale laboratory tests attempt to simulate end-use conditions and are conducted under the assumption that there is a relationship between test results and service performance. Valuable information about the fabrics used in protective clothing can be obtained from small scale tests; however, they do not necessarily predict how well garments or garment assemblies will perform when actually exposed to a flash fire.

Another method of evaluating protective garments is to expose a clothed instrumented mannequin to a controlled flash fire and to assess the resulting potential skin damage using computer models. An instrumented mannequin has been constructed at the University of Alberta for testing the thermal protective qualities of garments when subjected to short duration flash fires. Heat fluxes from 67 to 84 kW/m^2 (1.6 to 2 $cal/cm^2 \cdot s$) with burn durations of 3 to 4.5 seconds have been obtained reliably with the system. The University of Alberta's thermally instrumented mannequin is the only mannequin of its type in Canada and one of the few world-wide. Dale et al.(4) found there was good correlation of mannequin test results with TPP test results at low heat fluxes and durations, but not at higher values. Small scale tests are useful, however, as the first step in screening a large number of candidate materials before the best are selected for garment production and further testing.

The purpose of this research was to evaluate the relative effectiveness of different clothing assemblies comprising layers of differing materials (both FR and non-FR) in their contribution to protection against high heat flux flash fires. All garment systems were exposed to controlled simulated flash fires (80 or 84 kW/m^2) on a thermally instrumented mannequin. In addition, the multiple layers of fabrics which were used together in each of the garment systems were tested according to standard TPP tests.

2. MATERIALS AND METHODS

2.1 Garment Systems

In **experiment I, all-FR garment systems** were compared: system 1 comprising two layers (50/50 aramid/FR viscose underwear and aramid coveralls); system 2 comprising two layers (aramid/FR viscose underwear, aramid shirt and FR cotton pants); and system 3 comprising three layers (aramid/FR viscose underwear, aramid shirt and FR cotton pants, and aramid coveralls). Two replications of each system were tested.

In **experiment II**, two-layer systems were compared: system 4 comprising **FR outer** (aramid coveralls) and **FR inner** layers (aramid shirt and FR cotton pants); system 5 comprising **FR outer** (aramid coveralls) and **non-FR inner** layers (cotton shirt and pants); and system 6 comprising **non-FR outer** (cotton coverall) and **FR inner** layers (aramid shirt and FR cotton pants). Two replications of each system were tested. All garments used in experiments I and II were fabricated by the same manufacturer. The same coverall, shirt and pants patterns were used for the FR and non-FR garments, so that the fit on the mannequin was the same, regardless of the garment's fiber content. The garments used in experiments I and II are commonly worn by workers in the oil, gas, and petroleum industries.

In **experiment III**, six garment systems selected specifically for armed forces pilots were compared: three light-weight **FR flightsuits** (50/50 wool/aramid, 100% aramid, and 80/20 aramid/pbi) were each evaluated with **FR** (aramid tuckstitch knit) and **non-FR** (cotton tuckstitch knit) **underwear**. The three flightsuits were fabricated by the same manufacturer using a pattern supplied by the Canadian military; the two types of underwear were produced by two different manufacturers. Three replications of each system were tested.

Details of the fabrics used in the garment systems for each experiment are given in Tables 1 to 3.

2.2 Thermal Protective Performance Testing

The TPP test rates textile materials for thermal resistance and insulation when exposed to a convective energy level of about 84 kW/m^2 (2.0 $cal/cm^2 \cdot s$) for a short duration (5). Although it is not intended for evaluating materials exposed to any other thermal exposure such as radiant energy or molten metal splash, Day (6) has demonstrated that the source of heat flux is not as important as the method of specimen mounting. The basis of the test is to measure the time it will take to transfer sufficient heat through a fabric layer to cause second degree skin burns on a human under specified conditions. This is done by mounting the fabric over a copper slug calorimeter and bringing a gas flame on a standard burner into contact with the exposed surface of the fabric. The flame is adjusted to produce a heat flux of 2 $cal/cm^2 \cdot s$ measured with the copper slug calorimeter without a fabric present. The gaseous fuel used in this study was propane. The thermal protective performance (TPP) rating equals the exposure heat flux (2 $cal/cm^2 \cdot s$) x the exposure time in seconds required to transfer sufficient heat to produce second degree skin burns.

Multiple layers of fabrics, which were used together in each of the garment systems tested on the mannequin, were tested according to the TPP test [ASTM D4108-87 (5) as modified by CAN/CGSB-155.1-M88, Para. 6.1 (7)]. Restrained composite layer specimens with no spacer between the fabric and calorimeter were tested; results of five specimens were averaged. All fabrics were washed once following procedures outlined in CAN/CGSB-4.2 No. 58-M90 (8) to remove residual mill finishes prior to testing.

2.3 Mannequin Test

The instrumented mannequin was constructed of fibreglass by duplicating the shape of an existing male store mannequin, size 40R. Flash fires are produced with twelve propane diffusion flames. To measure the rate of heat transfer to the surface of the mannequin 110 skin simulant sensors are used. Output from the sensors is recorded for 60 seconds during and after flame exposure; this is used to calculate the percent skin surface area receiving 2nd and 3rd degree burns. A computer

TABLE 1. Experiment I: All-FR Garment Systems

System Code	Garment Layers	Fabric Layers (mass, g/m^2)*	Composite Mass g/m^2	Average TPP value	% Mannequin Surface Reaching Burn Criteria**			Mannequin Test Observations Ignition/Afterflame
					2nd°	3rd°	Total	
1	FR underwear FR coverall	aramid/FR viscose (256) aramid (198)	454	14.6	15.5	5.8	21.3	• brief afterflame <3 sec • shrinkage, color change in coverall • underwear shows at ankles as coverall shrank up the legs • underwear in good condition
2	FR underwear FR shirt	aramid/FR viscose (256) aramid (157)	413	13.4	24.7	8.8	33.5	• ~ 12 sec afterflame on pants • FR cotton pants charred • color change and some shrinkage in aramid shirt
	FR underwear FR pants	aramid/FR viscose (256) FR cotton (337)	593	10.8				
3	FR underwear FR shirt FR coverall	aramid/FR viscose (256) aramid (157) aramid (198)	611	20.2	1.4	6.3	7.7	• brief afterflame < 2 sec on sleeves and edges of pockets • shrinkage, color change in aramid coverall • underwear, pants and shirt in good condition
	FR underwear FR pants FR coverall	aramid/FR viscose (256) FR cotton (337) aramid (198)	791	20.7				

*CAN/CGSB-4.2 No. 5.1-M90 (9).

**Average of two replications. Includes unprotected head which is 7% of burn area; maximum total mannequin surface which may burn is 87% as hands and feet do not contain sensors.

TABLE 2. Experiment II: Systems Comprising FR and Non-FR layers

System Code	Garment Layers	Fabric Layers (mass, g/m^2)*	Composite Mass g/m^2	Average TPP value	% Mannequin Surface Reaching Burn Criteria**			Mannequin Test Observations Ignition/Afterflame
					2nd°	3rd°	Total	
4	FR shirt FR coverall	aramid (157) aramid (198)	355	11.3	5.1	5.8	10.9	• brief afterflame < 3 sec • shrinkage, color change in aramid coverall • garments underneath in good condition
	FR pants FR coverall	FR cotton (337) aramid (198)	535	12.8				
5	Non-FR shirt FR coverall	cotton (179) aramid (198)	377	10.8	4.3	4.8	9.0	• shrinkage and color change in aramid coverall • garments underneath in very good condition
	Non-FR pants FR Coverall	cotton (284) aramid (198)	482	12.0				
6	FR shirt Non- FR coverall	aramid (157) cotton (284)	441	13.5 flames	27.5	45.1	72.6***	• ~5 min of flames on the cotton coverall, followed by afterglow for ~ 20 min until coverall removed from mannequin and extinguished • pants charred under coverall, especially the left leg • aramid shirt intact but shrunken and discolored
	FR pants Non-FR coverall	FR cotton (337) cotton (284)	621	16.6				

*CAN/CGSB-4.2 No. 5.1-M90 (9).
**Average of two replications. Includes unprotected head which is 7% of burn area; maximum total mannequin surface which may burn is 87% as hands and feet do not contain sensors.
***Second replication omitted.

TABLE 3. Experiment III: Systems Comprising Light-Weight Flightsuits and FR vs Non-FR Underwear

System Code	Garment Layers	Fabric Layers (mass, g/m^2)*	Composite Mass g/m^2	Average TPP value	% Mannequin Surface Reaching Burn Criteria**			Mannequin Test Observations Ignition/Afterflame
					2nd°	3rd°	Total	
7	FR flightsuit I Underwear 1	50/50 FR wool/aramid (168) cotton tuckstitch (259)	427	16.1	18.1	8.5	26.6	• ~ 4-7 sec afterflame • underwear mostly intact except localized smoldering on leg cuffs & in 1 replication, a hole burned in upper left & below right buttocks • ~ shrinkage: 18 cm unrestrained & 5 cm restrained areas.
8	FR flightsuit I Underwear 2	50/50 FR wool/aramid (168) aramid tuckstitch (287)	455	17.3	6.4	7.4	13.8	• ~ 1-2 sec afterflame • underwear intact, discolored where outer layer is gone • ~ shrinkage as above
9	FR flightsuit II Underwear 1	aramid (193) cotton tuckstitch (259)	452	16.9	9.7	8.3	18.0	• ~ 0 - 0.5 sec afterflame • general overall shrinkage & color change • ~ shrinkage: 19.5 cm unre-strained & 8 cm restrained areas
10	FR flightsuit II Underwear 2	aramid (193) aramid tuckstitch (287)	480	19.2	4.2	7.4	11.6	• no afterflame • outerwear stuck to underwear • *general overall shrinkage & color* change • ~ shrinkage: 16 cm unre-strained & 9 cm restrained areas
11	FR flightsuit III Underwear 1	80/20 aramid/pbi (165) cotton tuckstitch (259)	424	16.7	5.0	8.3	13.3	• ~ 0.5 - 1 sec afterflame • ~ shrinkage: 14 cm unre-strained & 4.5 cm restrained areas
12	FR flightsuit III Underwear 2	80/20 aramid/pbi (165) aramid tuckstitch (287)	452	18.4	0.6	7.2	7.8	• ~ 0.5 - 1 sec afterflame • ~ shrinkage: 15 cm unre-strained & 5 cm restrained areas

*CAN/CGSB-4.2 No. 5.1-M90 (9).

**Average of three replications. Includes unprotected head which is 7% of burn area; maximum total mannequin surface which may burn is 87% as hands and feet do not contain sensors.

controlled data acquisition system is used to run the experiment, record and store the data, calculate the extent and nature of skin damage and display the results. A detailed description of the mannequin can be found in Dale et al. (4).

In three different experiments, garment systems which comprised different numbers of layers and which incorporated flame retardant (FR) and non-FR layers as outlined above, were exposed to a high heat flux. Experiment I and II conditions included an 84 kW/m^2 heat flux and a 4 second flame duration. In experiment III, exposure conditions included an 80 kW/m^2 heat flux and a 4.5 second flame duration.

3. RESULTS AND DISCUSSION

Results for **experiment I**, a comparison of all-FR systems, are given in Table 1. Two two-layer systems (systems 1 and 2), and a three-layer system (system 3) are compared. System 1 (FR coverall over FR underwear) resulted in a lower percent mannequin surface reaching second degree burns or greater than did system 2 (FR shirt and pants over the FR underwear). It is interesting to note that although the underwear and FR pants had the highest composite mass, they had the lowest TPP value. A typical skin-burn pattern on the mannequin for system 2 is shown in Figure 1. Adding a third layer (system 3) dramatically increased the thermal protection. When we consider that the unprotected head is 7% of the burn area, only 0.7% of the clothed mannequin reached second degree burns or greater when system 3 was worn. For experiment I, the TPP values are indicative of the relative mannequin test results for the three systems.

In Table 2, **experiment II**, two layer systems comprising FR and non-FR layers (systems 4, 5, and 6) are compared. When an outer FR coverall is worn, results vary little whether the inner layer is FR (system 4) or non-FR (system 5). When the non-FR layer is on the outside (system 6), however, the cotton coverall caught fire and resulted in 72.6% of the mannequin surface reaching second degree burns or greater (Figure 2). The coverall flamed for approximately 5 minutes followed by 20 minutes afterglow, at which time the coverall was removed from the mannequin and extinguished. The FR cotton pants worn under the cotton coverall charred, especially the left leg; the aramid shirt was intact but shrank and discolored. The second replication of this test was omitted for fear of damage to the mannequin system. The TPP results for system 6 would not predict the poor performance in the mannequin test. The TPP test is not intended to evaluate non-FR materials.

In Table 3, **experiment III**, six two-layer systems comprising three different light-weight FR flightsuits worn over FR and non-FR underwear are compared (systems 7 to 12). The total mannequin surface reaching second degree burns or greater was lowest for system 12 (aramid/pbi flightsuit in combination with the aramid underwear). Regardless of which type of underwear was worn, the aramid/pbi flightsuit afforded the greatest protection, followed by the aramid flightsuit; the FR wool/aramid provided the least protection. The FR wool/aramid flightsuit had a longer afterflame, had large portions of the outer fabric disintegrate completely on the front and back body, and had the greatest outer fabric shrinkage. A typical skin-burn pattern on the mannequin for system 7 is shown in Figure 3. On the basis of these results, such a light-weight wool blend is not recommended for flight crews.

In all cases, the aramid tuckstitch underwear performed better than the cotton tuckstitch underwear under the test conditions. The cotton underwear worn under the FR wool/aramid coverall exhibited some localized smoldering. If the flash fire had lasted longer than 4.5 seconds or the heat flux had been higher, this underwear might have ignited.

The TPP results do not differentiate among the three different flightsuit fabrics and thus would not predict either the superior performance of the aramid/pbi or the poorer performance of the wool/aramid blends in the mannequin test. Nor is the difference between the two types of underwear as great in the TPP test as it is in the mannequin test.

4. CONCLUSIONS

The protection provided by multiple layered garment systems is significantly greater than would be expected from the additive effects of the layers used singly. (Typical results for single layer coveralls of similar materials to those used in these experiments range from approximately 15 to 65 percent skin burn.). The outer layer of a garment system must be flame-retardant, however; wearing a flammable garment over a flame-retardant one clearly negates the benefits of the FR layer. While it cannot be concluded for certain that undergarments must also be flame-retardant, results demonstrate that wearing FR underwear offers more protection than wearing non-FR underwear, especially when worn under the relatively light-weight fabrics which may be used for military flightsuits.

Only in experiment I did the small-scale thermal protective performance tests indicate the relative protection provided by garment systems comprising all-FR layers. As expected, the TPP test did not indicate the potential hazard of systems in which the outer layer is non-FR. TPP results would not predict the relative protective properties of either the different flight-suit fabrics or the different underwear materials compared in experiment III.

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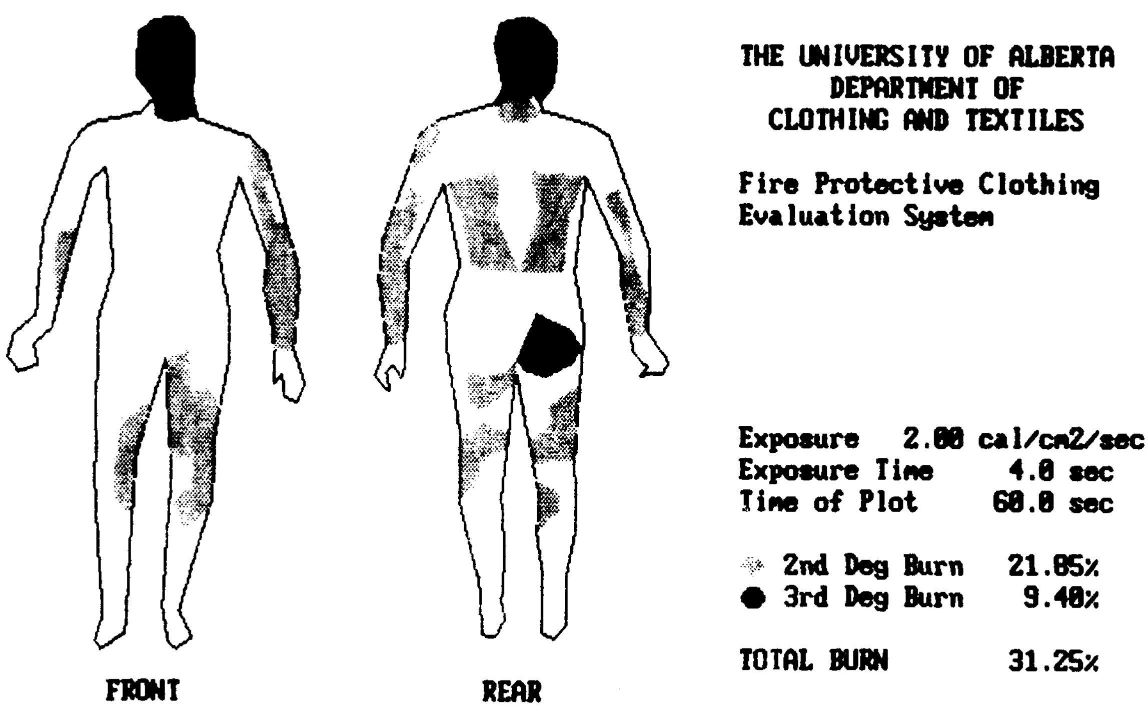

Figure 1. Predicted Percent Skin Damage when Mannequin is Dressed in System 2

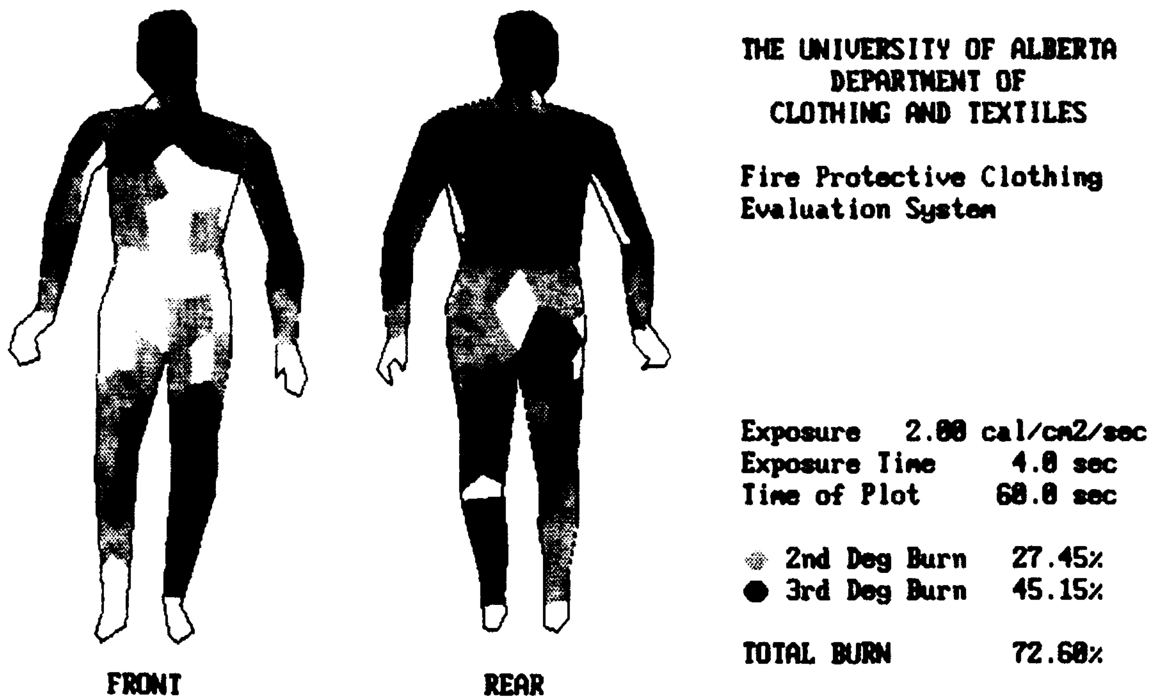

Figure 2. Predicted Percent Skin Damage when Mannequin is Dressed in System 6

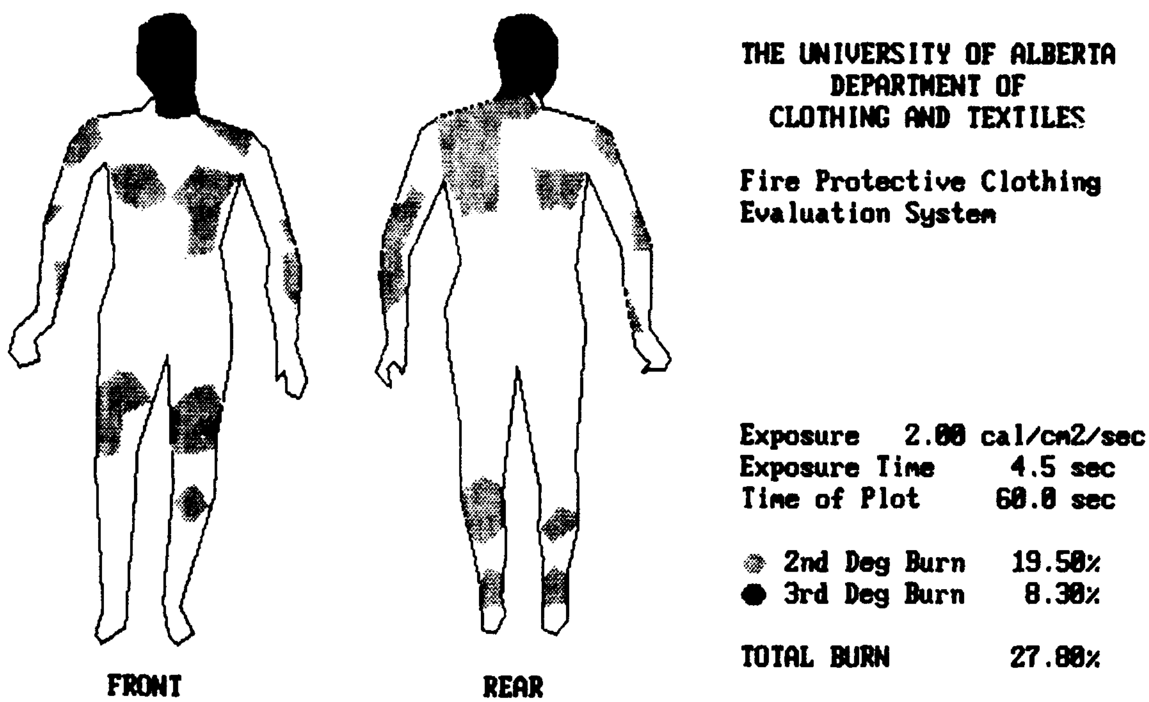

Figure 3. Predicted Percent Skin Damage when Mannequin is Dressed in System 7

DETERIORATION OF MANUAL PERFORMANCE IN COLD AND WINDY CLIMATES

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SUMMARY

Manual performance during work in cold and windy climates is severely hampered by decreased dexterity. In this study the quantitative performance decrease is investigated as a function of climatic factors. The decrease in finger- and hand dexterity and grip force was quantified for nine combinations of ambient temperature (-20, -10 and 0°C) and wind speeds (0.2, 4 and 8 ms^{-1}), controlled in a climatic chamber. Finger dexterity was determined by the Purdue pegboard test, hand dexterity by the Minnesota manual dexterity test and grip force by a hand dynamometer. Twelve subjects with average to low fat percentage were exposed to cold air for one hour with and without extra insulation by a parka. The subjects were clothed in standard work clothing of the Royal Netherlands Air Force for cold conditions.
Extra insulation did affect cold sensation but not manual performance. The deterioration (in %) in performance is strongly dependent upon Wind Chill Equivalent Temperature (°C), and exposure time (min). In a computer program the performance decrease and freezing risk is indicated for variable climatic conditions.

INTRODUCTION

The primary problem encountered during prolonged exposure to a cold environment is decrease dexterity. It has been shown that this may lead to an increased number of accidents (Müller, 1). An aircraft loading crew which is seriously affected by cold can unintentionally threaten the safety of the flying personnel. Therefore, directives are needed to indicate when a decrease in manual performance is to be expected so that a fresh crew can take over in time.

Factors influencing the exposure time are:
- climatic factors: ambient temperature, wind speed, solar radiation;
- personal factors: fat insulation, susceptibility to cold, metabolism, acclimatization;
- clothing insulation.

The combined effect of temperature and wind speed is quantified by the Wind Chill Index (WCI) and Wind Chill Equivalent Temperature (WCET). The WCI-term was first introduced by Siple and Passel (2) based on empirical data. Based on the WCI the 'subjective' temperature (WCET) could be calculated for a chosen reference wind speed. Later, Steadman (3, 4) calculated the WCET based on models of human heat transfer. Therefore, at the moment at least two different WCET-tables are used world wide with several reference wind speeds. The Royal Netherlands Meteorological Institute and the Meteorological department of the Royal Netherlands Air Force decided to take the WCET according to Steadman as a reference with a reference wind speed of 2 ms^{-1}.
In this study the climatic influence on dexterity is quantified by both the WCET of Siple and Passel ($WCET_{Si}$) and Steadman ($WCET_{St}$) with a reference wind speed of 2 ms^{-1}.
The subjects participating in the experiment were selected in such a way that their average fat percentage was just below the average. The subjects performed no exercise and were asked to sit quietly in order to reduce metabolic heat production. In this way a worst case situation was brought about.
Two different clothing insulation sets were compared, based on the winter clothing of the Royal Netherlands Air Force.
The results of the investigation have been translated in a computer program called WC (wind-chill) which enables calculation of the freezing risk and dexterity decrease during cold exposure.

Table I. Data of the investigated subjects. Body surface area is calculated according to Dubois and Dubois (5).

nr	age	weight	height	body surface	fat	hand volume L	hand volume R	hand surface L	hand surface R
	years	kg	cm	m^2	%	cm^3	cm^3	cm^2	cm^2
1	37	68	174	1.82	15.1	475	455	164	167
2	24	63	181	1.81	6.6	480	476	181	178
3	21	76	197	2.08	11.0	440	468	169	174
4	32	85	188	2.11	19.4	510	537	183	181
5	20	70	184	1.92	7.7	515	520	195	195
6	23	94	188	2.21	17.7	514	505	180	176
7	39	65	171	1.76	19.2	415	420	152	150
8	28	76	185	1.99	12.8	478	495	166	173
9	26	85	187	2.10	19.8	480	520	179	185
10	21	56	173	1.67	11.6	360	365	141	142
11	25	94	195	2.26	13.4	520	552	187	200
12	24	75	183	1.96	7.5	440	447	169	164
average	27	76	184	1.97	13.5	469	480	172	174
sd	6	12	8	0.19	4.8	48	53	15	16

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

MATERIALS AND METHODS

Twelve healthy males participated in the study. The subjects were fully informed of the purpose of the study and of their right to withdraw from experimentation at any time without prejudice and gave their written consent. The protocol was approved by the Ethical Committee of the Institute. The subjects were not exposed to cold prior to the experiment for a long period of time. The relevant data of the subjects is shown in Table I.
The volume and surface are not significantly different between the left and right hands (paired t-test, $P>0.05$).
The average fat percentage of the subjects was 13.5%. According to Fox and Mathews (6) the average for males is about 15 tot 17%, which means that this population has less fat than average.
This means that normative formulations about cold exposure times based on this population will be on the safe side.

Climatic conditions

Every subject visited the laboratory six or seven times (Appendix A). The ambient temperature was set to 0, -10 en -20°C and the wind speeds to about 0 - 0.5, 3.5 - 4.5 and 7.5 - 8.5 m/s (measured about one meter from the ground and about 20 cm in front of the face of the subject). This leads to nine different WCET values (Table II). The WCET of Siple and Passel (2) is much more influenced by wind speed than the WCET of Steadman (4).

Table II. Wind-chill equivalent temperatures of Siple and Passel (2) (SI) and Steadman (4) (ST) for the selected climatic conditions with a reference wind speed of 2 ms^{-1}.

Temp.(°C)	0		-10		-20	
WCET-index	SI	ST	SI	ST	SI	ST
wind speed (ms^{-1})						
0 - 0.5	+ 3	+ 2	- 6	- 8	-12	-17
3.5 - 4.5	- 6	- 2	-17	-12	-26	-23
7.5 - 8.5	-15	- 5	-29	-18	-39	-30

Dexterity determination

Immediately after entering the cold room the subjects were asked to sit on a chair. If the wind speed was about 4 or 8 ms^{-1} the subject was seated in the wind tunnel. If the wind was minimal the subject was seated in a shielded part of the climatic chamber.
Every twenty minutes the subjects performed three dexterity tests, starting about one minute after entering the cold room. The tests were:

1 Purdue Pegboard test. This test was shown to be well correlated to finger dexterity (7). In thirty seconds the subjects had to place as much pins in the board as possible with both hands. The subjects did not wear gloves during this test.
2 Minnesota Rate of Manipulation-Placing test, well correlated to hand dexterity (7). In 45 seconds the subjects had to place as many blocks as possible in the holes with both hands. The subjects were wearing leather gloves.
3 Maximal grip force, determined by the Jamar Deluxe Hand Dynamometer, model 0030J4. The distance between the handle bars was fixed to 5 cm. The force was determined with the arm stretched. The subjects were wearing leather gloves and synthetic mittens.

Hereafter, the subjects had to indicate the cold sensation on a list ranging form 8 to -8 with the texts 'very hot' (8), 'hot' (6), 'uncomfortably warm' (4), 'comfortably warm' (2), 'neutral' (0), 'comfortably cool' (-2), 'uncomfortably cool' (-4), 'cold' (-6) and 'very cold' (-8).
In addition, the experienced difficulty of the Minnesota test was asked for and rated on a nine point scale with the texts 'very easy' (1), 'easy' (3), 'neutral' (5), 'difficult' (7) and 'very difficult' (9).

During the periods that the subjects were not performing tasks in the cold room, they were sitting quietly with gloves and mittens over their hands. After the last test the subjects left the climatic chamber and stayed in a room of about 30°C for at least one hour to rewarm. The gloves, mittens, hat and parka were removed during the recovery period.

Clothing

During the experiments the subjects were wearing standard winter work clothing of the Royal Dutch Air force. This consisted of: thermal underwear, battle dress, warm overall, dickey, warm socks, work shoes, fur hat with ear flaps, leather gloves and 'trigger finger' mittens. Goggles were used to prevent freezing of the eyes. 'Camaches' were put around the ankles to prevent excessive air movement through the trousers. Every subject was exposed to cold with and without an additional parka. The thickness of the clothing parts was determined under a pressure of 100 Pa and these values were entered in the model of Lotens and Havenith (8) to determine the insulation values for a minimal wind speed. The insulation without a parka was 0.35 m^2K/W, the insulation with a parka was 0.38 m^2K/W.

Temperatures

Finger, toe and face temperature

The temperature of the left cheek bone and the ventral side of the distal phalanx of the left toe and left little finger was determined by a copper-constantane thermocouple. The sensor was fixed to the skin by 25 mm wide air permeable tape.

Rectal temperature (T_r)

Rectal temperature was continuously measured by a thermistor (YSI 701) inserted about 12 cm in the rectum.

Mean skin temperature ($\bar{T}_s$)

Three thermocouples were placed to calculate $\bar{T}_s$: on the sternum (T_{chest}), the belly of the biceps brachii (T_{arm}) and the medial vastus muscle (T_{leg}). $\bar{T}_s$ is calculated as

$$0.36\ T_{arm} + 0.25\ T_{chest} + 0.34\ T_{leg} + 1.19 \quad [1]$$

(9). This formula is validated against surface weighted calculation for 10 locations for a temperature range of 13 to 49°C and variable wind speed.

Mean body temperature ($\bar{T}_b$)

The mean body temperature is calculated by a formula by Farnworth and Havenith (10):

$$\bar{T}_b = 0.56\ T_r + 0.07\ \bar{T}_s + 0.04\ T_{finger} + 0.04\ T_{arm} + 0.145\ T_{toe} + 0.145\ T_{leg} \quad [2]$$

End of the experiment

The experiment was terminated when the subject or the experimenter indicated that the cold was no longer tolerable. Moreover, the experiment was terminated when rectal temperature was below 35°C or if one of the determined skin temperatures fell below 5°C. When the experiment was terminated, the subjects were removed from the cold immediately.

Statistics

First, the effects of the climatic conditions (WCET, exposure time and clothing insulation) upon local and central body temperature is investigated by multiple regression 10, 20, 30, 40 and 50 minutes after the start of the exposure.

Second, the relation between local and body temperature and dexterity (finger dexterity, hand dexterity and grip force) and subjective estimators (cold and difficulty) is investigated at minutes 20 and 40.

Finally, the direct effect of climatic conditions on dexterity and subjective cold and difficulty is investigated at minutes 0, 20, 40 and 60.

RESULTS

Drop-outs

The total number of sessions was: 12 (subjects) x 9 (WCET) x 2 (clothing) = 216. Two sessions were missed due to absence of the subjects, leaving 214 for the analysis.

In all 214 sessions the subjects stayed in the climatic chamber for at least 20 minutes. Twelve sessions were ended before the 40th minute and 36 before minute 60. The drop-outs were only found for low WCET-values (Fig. 1). At a $WCET_{St}$ of -30°C more than 80% of the population dropped out before 60 minutes exposure. Almost all sessions were ended due to toe temperature.

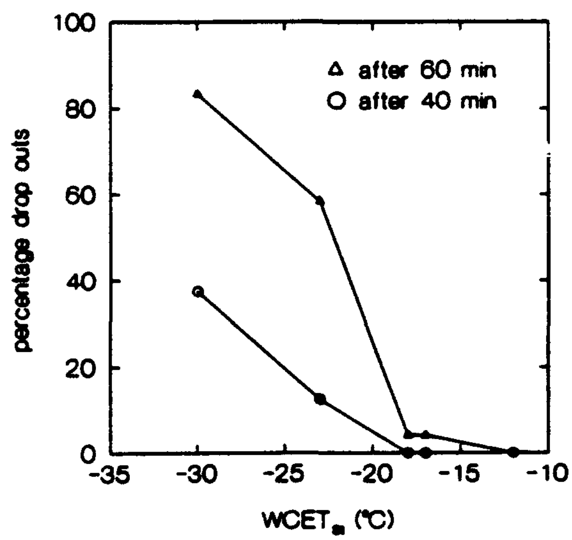

Fig. 1 Percentage drop-outs related to exposure time and Wind Chill Equivalent Temperature according to Steadman (4) ($WCET_{St}$). At $WCET_{St}$ of less than -18°C drop-out starts.

Effect of climate on body temperatures

The dependence of finger temperature (T_f), T_r and $\bar{T}_s$ of $WCET_{St}$, exposure time and clothing insulation is shown in Table III.

Table III. Regression equations of the relation between finger, rectal and mean skin temperature (in °C) and $WCET_{St}$, exposure time (min) and clothing insulation (in m^2K/W). r = multiple correlation coefficient. The results are averaged over twelve subjects. Significant contributions are underlined.

	C	$WCET_{St}$	time	insul	r
T_f	1.54	$\underline{0.44}$	$\underline{-0.17}$	$\underline{71.3}$	0.81
$\bar{T}_s$	$\underline{17.1}$	$\underline{0.12}$	$\underline{-0.04}$	$\underline{46.6}$	0.84
T_r	$\underline{37.3}$	$\underline{-0.01}$	$\underline{-0.003}$	-0.43	0.78

T_f as well as $\bar{T}_s$ decrease when $WCET_{St}$ decreases, while T_r shows a small increase. Possible causes for this unexpected phenomenon are treated in the discussion.
T_f, T_s and T_r decrease when exposure time increases. The extra parka causes a higher T_f and T_s.

The $WCET_{Si}$ shows higher correlations with T_f (0.89) and $\bar{T}_s$ (0.93) than $WCET_{St}$. A lower correlation is found for T_r (0.64). T_b was very dependent upon $WCET_{St}$ or $WCET_{Si}$ and exposure time (Fig. 2): the multiple regression correlations were 0.84 and 0.92 respectively. In Fig. 2 it can be seen that T_b was relatively high in the situation with minimal wind speed. Otherwise stated: the $WCET_{St}$ should have been higher with low wind speeds. If only the wind tunnel experiments were analyzed the multiple regression coefficient would have been 0.97 for $WCET_{St}$!

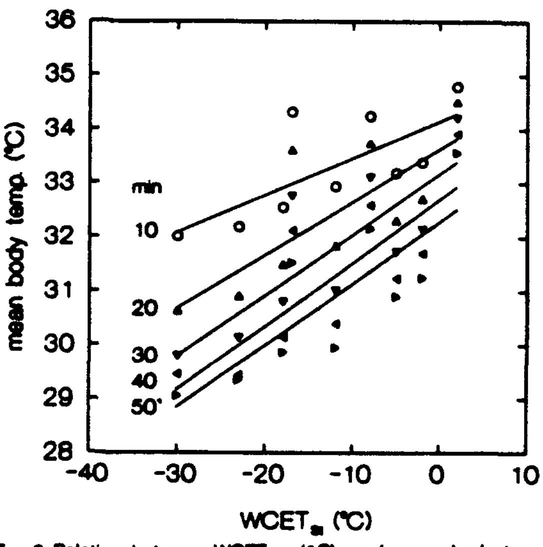

Fig. 2 Relation between $WCET_{St}$ (°C) and mean body temperature ($\bar{T}_b$ in °C) determined by Farnworth and Havenith (10) for several exposure times. o = 10 minutes, ▲ = 20 minutes, ▼ = 30 minutes, ◄ = 40 minutes and ► = 50 minutes exposure time.

Effect of temperature on performance

The performance on the tests and the subjective scores were related to T_f, T_r and $\bar{T}_s$. The relation between T_f and finger dexterity is shown in Fig. 3. At finger temperatures of less than 14°C the performance decreases. The drop-outs at low T_f may even cause underestimation of the dexterity decrease at low temperatures.

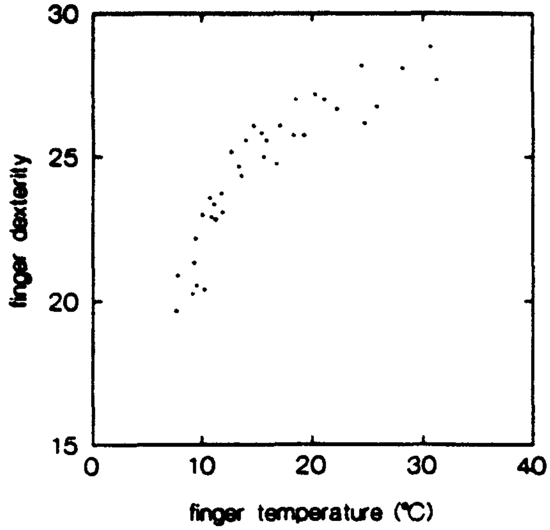

Fig. 3 Relation between finger temperature (°C) and finger dexterity (determined by the Purdue Pegboard test). The values are averaged over twelve subjects. Each point stands for a measurement at a fixed WCET after 20 or 40 minutes exposure time with or without a parka.

T_f and $\bar{T}_s$ are strongly related (r = 0.91). Therefore, only $\bar{T}_s$ is considered in the statistical analysis of Table IV.

Table IV. Regression equations of the test score related to rectal (T_r) and mean skin ($\bar{T}_s$) temperature. C = constant, r = multiple correlation coefficient. Results are averaged over twelve subjects. The influence of every factor is significant.

	factor			
	C	$\bar{T}_s$	T_r	r
finger dexterity	184.0	1.1	-5.2	0.93
hand dexterity	252.1	1.4	-6.9	0.89
hand grip force	358.6	0.7	-9.0	0.79
cold score	69.99	1.2	-3.0	0.96
diff. hand dext.	-33.59	-0.4	1.3	0.91

Dexterity is better for a high $\bar{T}_s$ (and T_f) and a low T_r. In the preceding paragraph it is shown that T_r is high for a low WCET, which makes the net effect of WCET on dexterity positive again. The subjective scores show an identical image to dexterity: the situation is assessed colder and more difficult when $\bar{T}_s$ decreases and T_r increases.

There was a distinct relation between $\bar{T}_b$ and performance. In Table V the correlations are shown between $\bar{T}_b$ and performance. The method of $\bar{T}_b$-calculation by Farnworth and Havenith (10) showed a better correlation with performance than the conservative method weighing only rectal and mean skin temperature with appropriate weight factors for a cold body (0.6 T_r + 0.4 $\bar{T}_s$).

Table V Correlation between mean body temperature calculated by T_r and $\bar{T}_s$ (first column) and by Farnworth and Havenith (10) (second column) and the test scores.

mean body temperature	T_r, $\bar{T}_s$	Farnworth and Havenith (10)
finger dexterity	0.82	0.90
hand dexterity	0.78	0.86
hand grip force	0.53	0.66
cold score	0.91	0.95
diff. hand dext.	0.83	0.86

In Fig. 4 the relation between $\bar{T}_b$ and finger dexterity is shown.

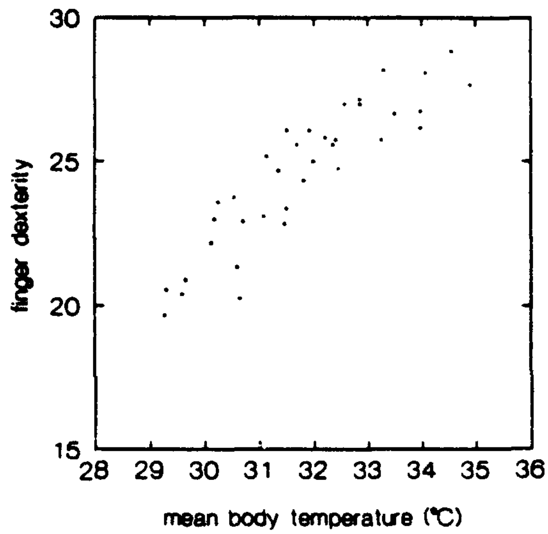

Fig. 4 Relation between mean body temperature (°C) calculated by Farnworth and Havenith (10) and finger dexterity, determined by the Purdue Pegboard test.

The fat percentage of the subjects has no relation with the scores on the finger and hand dexterity tests. Also the correlations of fat percentage with grip force, cold score and assessed difficulty were below 0.21.

Direct effect of climatic factors on dexterity

Absolute decrease in dexterity

The scores were dependent upon $WCET_{St}$, exposure time and their interaction term. The scores on the tests were not dependent upon clothing insulation or the interaction between exposure time and clothing insulation. The regression equations were (significant contributions are underlined):

finger dexterity (number of pins in Purdue board in 30 s) = $\underline{27.837}$ + $\underline{0.082}$ * $WCET_{St}$ - $\underline{0.023}$ * time + $\underline{0.003}$ * $WCET_{St}$ * time (r = 0.90) [3]

hand dexterity (number of blocks in Minnesota board in 45 s) $= \underline{42.099} + \underline{0.138} * WCET_{St} - 0.020 * time + \underline{0.006} * WCET_{St} * time$ (r = 0.92) [4]

hand grip force (kgf) $= \underline{46.100} + \underline{0.175} * WCET_{St} - 0.028 * time + 0.000 * WCET_{St} * time$ (r = 0.76) [5]

For all tests the performance decreases when $WCET_{St}$ decreases. Hand grip force is less deteriorated by exposure time than finger and hand dexterity.

If $WCET_{Si}$ was taken as the base of calculations in stead of $WCET_{St}$ the correlations for finger and hand dexterity would have been higher (0.93 and 0.97 respectively) but lower for hand grip force (0.71).

In Fig. 5 the relation between hand dexterity and $WCET_{St}$ is shown for four different exposure times. The interaction is clearly visible by the convergence of the lines. For the least stressful climatic condition, the dexterity increases when exposure time is prolonged. This implicates that the point of intersection can be seen as the climatic condition in which the dexterity is independent of the exposure time.

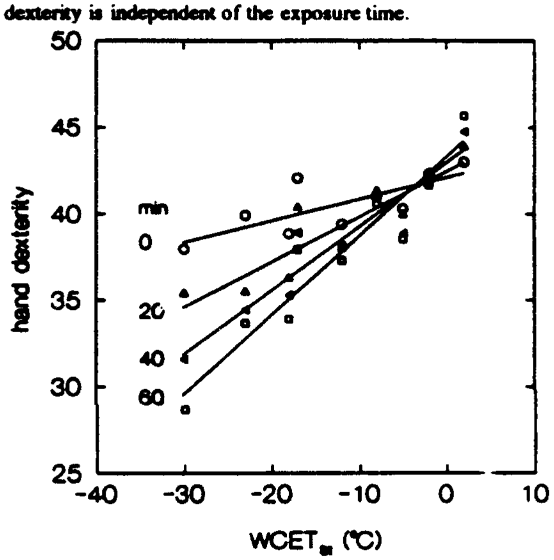

Fig. 5 Relation between WCET according to Steadman (4) and hand dexterity, determined by the Minnesota test. The four lines are regression lines for exposure time. The symbols stand for: o=0 minutes, ▲=20 minutes, ◄=40 minutes and □=60 minutes exposure time.

Relative performance decrease

In order to be able to indicate the percentage performance loss during exposure to cold and wind, the scores are normalized for the tests. This is accomplished by averaging the performance over WCET, performance time and clothing insulation and setting this average to 100% for every subject. Hereafter, the formula's are transformed in such a way that the performance at 0°C $WCET_{St}$ and start of exposure is set to 100%.

In the regression analysis exposure time was not significant as a main effect, and therefore omitted in the regression equation. The model is applied on the data set of subject means and counts 72 data points (9 WCET * 4 exposure times (0, 20, 40 and 60 minutes) * 2 clothing insulation values). The percentual performance decrease is:

finger dexterity decrease (%) $= -0.24 * WCET_{St} - 0.021 * WCET_{St} * time$ [6]

Hand dexterity decrease (%) $= -0.42 * WCET_{St} - 0.016 * WCET_{St} * time$ [7]

Hand grip force decrease (%) $= -0.25 * WCET_{St} - 0.010 * WCET_{St} * time$ [8]

For a $WCET_{St}$ of -10°C and an exposure time of 30 minutes a decrease in dexterity of fingers and hands of about 9% can be expected, and about 6% force deterioration. At longer exposure times the finger dexterity will deteriorate more than hand dexterity. The computer program takes these regression lines as a base of calculation of performance decrease.

Cold and difficulty assessment

The subjective cold score is lower for the least insulating clothing ensemble. The scores are dependent upon $WCET_{St}$, exposure time and their interaction. The subjective difficulty of the Minnesota test is not related to clothing insulation but only to $WCET_{St}$ and the interaction with exposure time:

Cold score $= -12.8 + 0.15 * WCET_{St} + 0.001 * WCET_{St} * time - 0.048 * time + 39.0 * I$ (r=0.91) [9]

Difficulty $= 2.9 - 0.024 * WCET_{St} - 0.001 * WCET_{St} * time$ (r=0.88) [10]

in which I stands for the clothing insulation (in $m^2 \cdot K/W$).

Influence of wind and speed combination on performance

The WCET incorporates a certain combination of ambient temperature and wind speed. If the performance is explained by temperature and wind as main effects and their interaction term the correlation is slightly higher than for both investigated WCET's (Table VI).

Table VI. Correlation between performance / subjective scores and three different indices for climatic conditions. The first index incorporates ambient temperature, wind speed and exposure time and their interactions. The second term the WCET according to Siple and Passel (2), exposure time and their interaction and the third index the WCET according to Steadman (4), exposure time and their interaction.

	index		
	temp./wind and time	$WCET_{Si}$ and time	$WCET_{St}$ and time
finger dexterity	0.93	0.93	0.90
hand dexterity	0.97	0.97	0.92
hand grip force	0.80	0.71	0.76
cold score	0.94	0.93	0.88
diff. hand.test	0.95	0.93	0.88

The first index shows the highest correlation with performance. The disadvantage of this index is the number of terms: besides the three main terms four interactions terms are in the regression equation. The explained variance of the WCET's in not much worse than that of the first index and has fewer terms. The $WCET_{Si}$ shows a better overall relation than $WCET_{St}$, possibly because the latter underestimates the influence of wind.

Order effects

The design was balanced for ambient temperature, wind speed, clothing and time of day (morning, afternoon). Therefore, order effects are excluded. A data plot of the test performance against experiment number (Fig. 6) reveals that the balanced design was certainly needed because a learning curve is clearly present for finger dexterity and in particular hand dexterity.

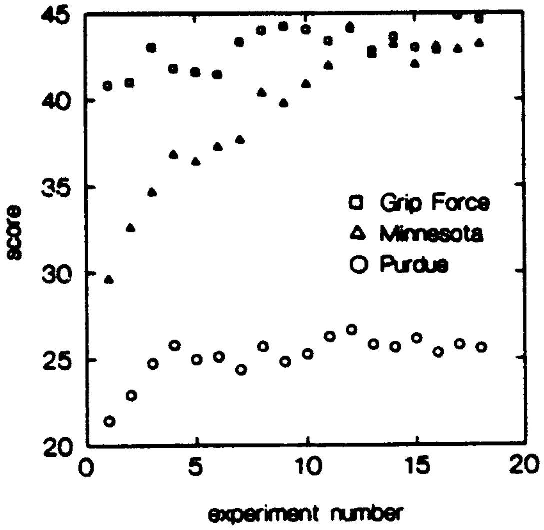

Fig. 6 Relation between experiment number and the absolute scores on the finger dexterity test (number of pins set in the Purdue Pegboard in 30 seconds), hand dexterity test (number of blocks set in the Minnesota board in 45 seconds) and hand grip force (in kgf). Values are averaged over twelve subjects.

DISCUSSION

Effect of climatic factors on temperatures

It was found that the core temperature was higher when $WCET_{St}$ was lower. This seems contradictory. Two possible explanations are given below.
First, the low $WCET_{St}$ might have caused a strong peripheral vasoconstriction ('physiological amputation'), which cause peripheral circulation to be minimal thus preventing cold blood going to the body core. In combination with the enhanced metabolism, this might have caused the increased T_r.
Second, the subjects, knowing they were entering a cold environment, might have anticipated upon this by raising their activity level in the resting period. An analysis showed that this might indeed have been the case: the average T_r during the initial five minutes in the climatic chamber was 37.07 ± 0.09°C for $WCET_{St}$ > -10°C and 37.30 ± 0.10°C for $WCET_{St}$ < -15°C.

Effect of climatic factors on performance

It is shown in the results that the performance on dexterity tests is deteriorating under a certain value of $WCET_{St}$, but decreases linearly with $WCET_{St}$. Even in the first measurement, starting about a minute after entering the climatic chamber, a $WCET_{St}$ effect is visible in the finger dexterity. The exposure time of the hand grip test and hand dexterity test is even longer because they were preceeded by other test(s).

Clothing insulation

Clothing insulation had a strong influence on the subjective cold score, but did not influence performance. The difference in insulation by the parka was about 0.2 Clo, and probably insufficient to influence performance.

Work load

The experiment was performed with minimal work load: the only work performed was the displacement of the pins or blocks or one bout of maximal voluntary contraction. In this situation performance decrease is expected to be maximal compared to situations in which humans are warmed by continuous exercise. So, the results can be interpreted as the worst condition. Moreover, in reality dexterity tasks are very often performed in a situation in which exercise is minimal.

Sunshine

Steadman (4) calculated the effects of full sunshine (135 Wm^{-2}) on the $WCET_{St}$. For temperatures below 0°C the effect of sunshine is dependent on wind speed and almost independent on ambient temperature. For minimal wind speed about 7°C has to be added to the $WCET_{St}$, for a wind of 20 ms^{-1} about 3°C has to be added. The developped computer-program offers the possibility to correct for sunshine.

Performance decrease

Teichner (11) is one of the few who related dexterity to wind-chill. His subjects had to perform tasks after a 25 minute exposure to cold in well insulated clothing and with gloves on. The dexterity tasks were performed without hand protection. If his results are recalculated to a $WCET_{St}$ with a reference wind speed of 2 ms^{-1}, a performance decrease was found at $WCET_{St}$ lower than -18°C. The finger temperature was then just below 14°C. In Fig. 3 it is shown that also in our investigation finger dexterity decreased when finger temperature fell below 14°C. In our study finger and hand dexterity decreased by 15% after an exposure of 25 minutes to -18°C $WCET_{St}$.

In 1962 Clark and Jones (12) showed that dexterity decreased during cold exposure, and that this decrease had a cold specific training effect. Subjects trained for their tasks in a cold environment performed better than subjects trained in a warm environment and then performing in the cold. In our investigation cold and wind were balanced, thereby excluding temperature specific training effects.

Relation between $WCET_{St}$ and cold sensation

In 1991 Dixon (13) combined $WCET_{St}$ isotherms with cold sensation scores (2) (Fig. 7).

In contrast to the reference wind speed of 2 ms^{-1} which is choosen in the Netherlands, Dixon (13) took 0 ms^{-1} as a reference. By linear regression a reasonable approximation can be given of the $WCET_{St}$ at a reference speed of 2 ms^{-1}. The regression equation is:

$$WCET_{St}\ (v_{ref} = 2\ ms^{-1}) = 1.117 * WCET_{St}\ (v_{ref} = 0\ ms^{-1}) + 3.948 \quad [11]$$

With the recalculated $WCET_{St}$ values Table VII is constructed to indicate the relation with cold sensation.

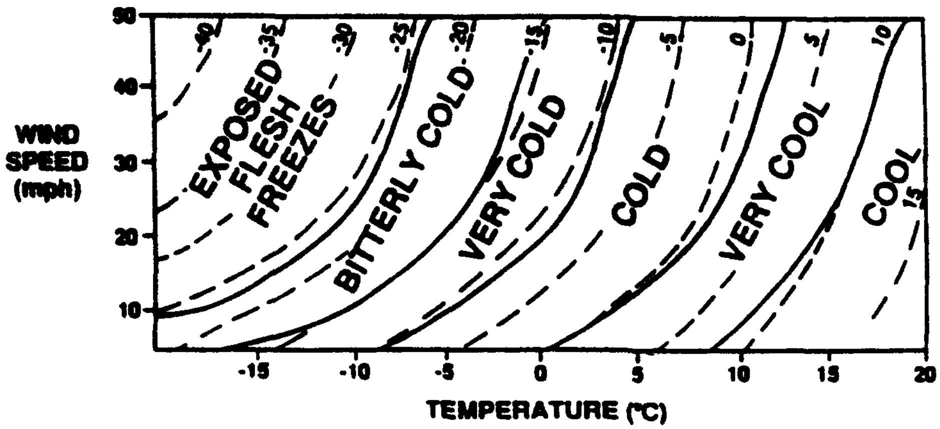

Fig. 7 Relation between cold sensation (continuous lines) and wind-chill equivalent temperatures according to Steadman (dotted lines) in °C, in a plot with ambient temperature (°C) on the abcissa and wind speed (mph) on the ordinate (from: Dixon, 13).

Table VII The relation between wind-chill equivalent temperatures according to Steadman ($WCET_{St}$ in °C) and cold sensation.

$WCET_{St}$	Cold sensation
<-24	Freezing cold
-24 to -13	Bitterly cold
-13 to -7	Very cold
-7 to 4	Cold
4 to 15	Very cool

From our investigation it is clear that more factors than $WCET_{St}$ determine the cold sensation. Clothing insulation and exposure time also play an important role.

Freezing danger

The most often used indicator for freezing danger is based on the work of Siple and Passel (2) and Terjung (14). In this paragraph the established thresholds are recalculated to the $WCET_{St}$ with a reference wind speed of 2 ms^{-1}.

In Table VIII combinations of wind speed and air temperature are shown above which the WCI of Siple and Passel is equal to 1625 Wm^{-2}. Above this value Terjung found a great freezing danger. In the last column the corresponding $WCET_{St}$ is given derived from the Table in Appendix B.
At wind speeds higher than 4 ms^{-1} the freezing danger is present for a $WCET_{St}$ of less than -22°C. This value is close to the $WCET_{St}$ value below which the cold sensation is called 'freezing cold' (-24°C) in Table VII.

Tabel VIII Ambient temperatures (°C) and wind speeds (ms^{-1}) at which the freezing danger is great. The data are based on Terjung (14). The corresponding wind-chill equivalent temperature (in °C) according to Steadman (4) is given in the right hand column.

wind speed	ambient temperature	$WCET_{St}$
0.2	-62.2	N.A.
2	-29.0	-29
4	-20.0	-23
6	-15.4	-21
8	-12.6	-22
10	-10.7	-22
12	- 9.3	-22
14	- 8.4	-23
16	- 7.7	-22
18	- 7.2	-23
20	- 6.8	-23

Wet hands

All subjects had dry hands during the investigation. In practice tasks might be performed during which the hands are wet. The evaporative heat loss will cause extra loss of dexterity.

The dry heat transfer from the hands can be written as:

$$H_{dry} = (h_c + h_r) * \Delta T \ (Wm^{-2}) \qquad [12]$$

in which ΔT is the temperature difference between skin and environment and h the dry heat transfer coefficient of convection (h_c) and radiation (h_r).

The wet heat transfer is:

$$H_{wet} = h_e * \Delta P \ (Wm^{-2}) \qquad [13]$$

in which ΔP stands for the difference in partial water pressure on the skin and in the air and h_e for the wet heat transfer coefficient.

The relation between h_e and h_c is given by:

$$h_e = L * h_c \ (Wm^{-2} \cdot Torr^{-1}) \quad [14]$$

L (Lewis constant) is 2.2 (°C·Torr^{-1}) for laminar air stream. ΔP and ΔT are closely related when the ambient temperature is lowered with equal relative humidity. Since h_e is about twice as large as h_c the wet heat transfer is twice the convective part of the dry heat transfer. The radiation part of the dry heat transfer is almost equal to h_c if wind speed is close to zero and neglectable with high wind speeds. This means that the total heat transfer of the hands ($h_c + h_r + h_e$) is about twice the dry heat transfer ($h_c + h_r$) in a condition without wind and almost three times as great in windy conditions. This means that hands will cool stronger when they are wet and when there is a strong wind, and thus deteriorate performance in an earlier stage. In the computer program the dexterity decrease for wet hands is also assessed.

The calculations above are only valid for continuously wet hands. When the hands got wet only once, about 3 g water sticks to one bare hand. Evaporation climates 3 * 2430 J = 7 kJ heat from the hand. If the water is completely evaporated in five minutes, the mean heat loss is 25 W. The hand has a surface area of about 0.05 m^2. This means that the heat loss from a hand is about 500 Wm^{-2}.

CONCLUSIONS

During cold exposure finger and hand dexterity and grip force decrease linearly with $WCET_{St}$. The longer the exposure time the greater the performance decrease. Dexterity is decreased by about 15% after an exposure time of 30 minutes to -18°C $WCET_{St}$.
By calculation it is shown that the heat loss of the hands is two to three times higher when the hands are continuously wet and a corresponding dexterity decrease will probably appear within 15 minutes.
The mean body temperature ($\bar{T}_b$) can be considered as an important physiological intermediate between climatic conditions and performance. Both T_f and T_s are lower when exposure time is prolonged and $WCET_{St}$ and clothing insulation are reduced. When T_f droppes below about 14°C finger dexterity is severely impaired.
The cold sensation is strongly related to $\bar{T}_s$. The experienced difficulty of the hand dexterity test is not dependent upon clothing insulation, but a good representation of the dexterity decrease.
From the literature it is derived that at $WCET_{St}$ values of less than -22°C a danger for freezing of the bare skin exists. Close to this $WCET_{St}$ value subjects report to feel 'freezing cold'.

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APPENDIX A - Experimental set-up

Time schedule on a full day (for instance day 2)

	wind tunnel		wind free tunnel	
time	s	cl	s	cl
8.15 - 9.20	1	1	7	1
9.25 - 10.30	2	2	8	2
10.35 - 11.40	1	2	7	2
11.45 - 12.50	2	1	8	1
12.55 - 14.00	7	2	1	2
14.05 - 15.10	8	1	2	1
15.15 - 16.20	7	1	1	1
16.25 - 17.30	8	2	2	2

Schedule of measuring days

	am/pm	subject	temp	wind
day 1	am	1,2	-20	8
day 1	am			
day 1	pm	7,8	-20	8
day 1	pm			
day 2	am	1,2	-20	4
day 2	am	7,8	-20	0
day 2	pm	1,2	-20	0
day 2	pm	7,8	-20	4
day 3	am	3,4	-10	0
day 3	am	9,10	-10	8
day 3	pm	3,4	-10	8
day 3	pm	9,10	-10	0
day 4	am	3,4	-10	4
day 4	am			
day 4	pm	9,10	-10	4
day 4	pm			
day 5	am	5,6	0	4
day 5	am			
day 5	pm	11,12	0	8
day 5	pm	5,6	0	0
day 6	am	5,6	0	8
day 6	am	11,12	0	0
day 6	pm	11,12	0	4
day 6	pm			
day 7	am	5,6	-20	0
day 7	am	9,10	-20	4
day 7	pm	5,6	-20	8
day 7	pm			
day 8	am	9,10	-20	8
day 8	am			
day 8	pm	5,6	-20	4
day 8	pm	9,10	-20	0
day 9	am	1,2	-10	4
day 9	am			
day 9	pm	11,12	-10	4
day 9	pm			
day 10	am	1,2	-10	0
day 10	am	11,12	-10	8
day 10	pm	1,2	-10	8
day 10	pm	11,12	-10	0
day 11	am	3,4	0	8
day 11	am			
day 11	pm	7,8	0	4
day 11	pm			
day 12	am	3,4	0	4
day 12	am	1,2	0	0
day 12	pm	7,8	0	8
day 12	pm	3,4	0	0
day 13	am	3,4	-20	4
day 13	am	11,12	-20	0
day 13	pm	3,4	-20	0
day 13	pm	11,12	-20	4
day 14	am	3,4	-20	8
day 14	am			
day 14	pm	11,12	-20	8
day 14	pm			
day 15	am	5,6	-10	8
day 15	am	7,8	-10	0
day 15	pm	5,6	-10	4
day 15	pm			
day 16	am	7,8	-10	4
day 16	am			
day 16	pm	5,6	-10	0
day 16	pm	7,8	-10	8
day 17	am	1,2	0	8
day 17	am	9,10	0	0
day 17	pm	1,2	0	4
day 17	pm	7,8	0	0
day 18	am	9,10	0	4
day 18	am			
day 18	pm	9,10	0	8
day 18	pm			

clothing 1 = without parka
clothing 2 = with parka
wind = wind speed in m/s
temp = ambient temperature in °C
s = subject
cl = clothing

Appendix B Steadman Wind-chill equivalent temperatures (reference speed = 2 ms^{-2}).

Bft	Wind-speed		Ambient temperature °C																
	kts	m/s	+8	+6	+4	+2	0	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24
2	4	2	+8	+6	+4	+2	0	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24
3	8	4	+7	+5	+3	+1	-2	-4	-6	-8	-11	-12	-15	-17	-19	-21	-23	-25	-27
4	12	6	+6	+4	+2	-1	-4	-6	-9	-10	-13	-15	-18	-20	-22	-24	-27	-28	-31
5	16	8	+5	+3	0	-3	-5	-8	-11	-12	-16	-18	-21	-23	-26	-28	-30	-32	-34
	20	10	+4	+2	-1	-4	-7	-10	-13	-15	-18	-21	-23	-27	-29	-32	-34	-36	-37
6	24	12	+3	+1	-2	-6	-9	-12	-15	-17	-20	-23	-27	-29	-32	-34	-37	-38	-41
	28	14	+2	0	-3	-7	-10	-13	-16	-18	-22	-25	-29	-32	-35	-37	-40	-42	-44
7	32	16	+2	-1	-4	-8	-11	-14	-18	-19	-23	-27	-31	-34	-37	-39	-42	-44	-46
8	36	18	+1	-2	-5	-9	-12	-16	-19	-21	-25	-29	-33	-37	-39	-42	-44	-47	-48
	40	20	0	-3	-5	-9	-13	-16	-19	-22	-26	-30	-34	-37	-41	-43	-46	-48	-51

EFFECTIVENESS OF PROTECTION CLOTHING FOR COLD WEATHER CONDITIONS AFTER EJECTION OVER SEA - A CASE REPORT

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SUMMARY

During a night formation mission including an approach without establishing a connection to the tanker aircraft a collision of both aircrafts, Typ PA 200 - Tornado occurred. The four aircrew members performed an ejection. The site of accident is located over the baltic sea in the Skagerrak region. At the time of accident the air temperature was noted with 6°C, the water temperature with 11°C, the sea with waves of 4 to 4.5 m height with a frequency of 8 waves per minute. The time of rescue ranged from 1 hour 28 minutes to 2 hours 14 minutes. It will be reported on clothing and personal equipment, on the clinical findings and on statements of the crew members. The crew member who was recovered after 2 hours and 14 minutes did not survive. This accident shows that with the ordered clothing a survival under these conditions is supported, yet with incomplete equipment it must be reckoned with a fatal outcome. Further details are discussed.

INTRODUCTION

In contrast to the Air Force, naval air wings fly over the areas of the North Sea and the Baltic Sea most of the time. The dangers arising from flying over the sea are associated with the environment, the voluminous equipment of the crews and the fact that rescue times after ejection may be long.
It will be reported about an aircraft accident which happened in the autumn of 1991. During night flying training, two PA 200 collided over the Skagerrak. The four crew members managed to eject. One Weapon System Operator died from hypothermia.

PREPARATION OF THE FLIGHT

At the end of October 1991, the flight mission was to fly a coordinated attack in a defined area over the sea over the Skagerrak at night. Two aircraft, one of them equipped as a tanker airplane, had additionally been tasked to practice night formation flying. The aircraft which was to simulate being refueled was to fly approach maneuvers to the tanker aircraft without docking.
In addition to the general briefing on night flying, there were briefings on the rendezvous technique, formation exercises and the carrying of lights of the aircraft.
In the course of the briefing, the pilot of the tanker aircraft suggested that he change the lights of his aircraft himself and not only upon demand by the approaching aircraft as laid down in the regulations.

FLIGHT AND WEATHER DURING THE ACCIDENT

The flight was carried out according to the preflight briefing.

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

The aircraft were at an altitude of approximately 4,000 ft. Since the first rejoin maneuver had not functioned optimally as far as timing was concerned and more than 15 minutes were left, the WSO of the receiving aircraft decided to repeat the rejoin process. The tanker aircraft was flying at a constant 260 - 270 KIAS. At first, the receiving aircraft was flying at a speed of 350 KIAS and then reduced its speed to 300 KIAS. Once the receiving aircraft had reached a position of one NM behind, 30° staggered to the left and 200 ft below the altitude of the tanker aircraft flying in front, the approach maneuver was to be carried out visually. The pilot of the receiving aircraft was now looking for the navigation light, the wing obstruction lights and the fin/rudder assembly obstruction lights as well as the anticollision light. In the course of the further approach, all lights of the tanker aircraft except the white obstruction light at the fin/ rudder assembly suddenly went out. Consequently, the pilot of the receiving aircraft was no longer able to estimate the tankers attitude in space, its distance to himself or his own rate of approach. He asked the pilot of the tanker aircraft to switch the anticollision light back on and later reported that "the white light at the fin assembly grew alarmingly bigger and suddenly everything looked so different, not like before. I pushed the aircraft down and then there was a crash." After the collision, all crew members used their ejection seats to escape from the disabled air- raft.

At the time of the accident, the temperature of the air was 5 - 7°C (approx. 41 - 45°F), the dew point was at 6°C (approx. 43 °C) and the water temperature was 11°C (approx. 52 °F). According to reports, the wave height was 4 - 4.5 m, the wave period was 8 seconds and the wind speed was 35 knots from an angle of 150°. There was haze, and visibility was 4 km with broken clouds at an altitude of 2,000 ft. The haze ceiling was reported to be 2,000 ft. Above, visibility was 10 km or more. As the moon was on the wane, it was very dark but the sky was starry (Fig. 1).

REPORT OF THE ACCIDENT

Approximately one minute after the collision, another PA 200, which had at first been flying over the Baltic Sea and was to discover the disabled aircraft later, picked up the emergency radio signals and informed Kopenhagen-Radar. Kopenhagen alerted the SAR readiness service in Ahlborg, and about half an hour after the collision, a Seaking SAR heli- copter took off and flew in the direction of Jammerbucht. Almost one hour after the collision, the helicopter picked up the emergency radio signals.

RESCUE OF THE FOUR CREW MEMBERS

Roughly 1 hour and 10 minutes after the collision, the SAR helicopter arrived at the site of the accident. 8 minutes later, the SAR helicopter found the first of the crew members. The four crew members where rescued by means of air rescue and the double winch method, which was impeded by strong wind and heavy sea, after the following times (fig.2):
The first crew member was rescued after 1 hour and 28 minutes, the second one after 1 hour and 34 minutes and the third one after 2 hours and 2 minutes. All of those three crew members had been in their sea rescue boats.
The fourth crew member was found drifting lifelessly in the sea without a dinghy and

approximately 2 NM away from the others. He was rescued after 2 hours and 14 minutes. Resuscitation was given in the helicopter until it arrived at the Thistedt hospital.In Ahlborg, the three other crew members were handed over to the German SAR crew which had arrived by then.
The life raft of the crew member who had been rescued last was not found at first. Two days later, it was salvaged on the Norwegian coast. The splash cover was filled with water, the bottom was partly inflated. As was found out later, the dinghy lanyard had torn over a sharp edge due to the application of strong force approximately at the point where it leads into the interior of the dinghy. It may be assumed that the WSO had first climbed into his rubber boat after ejection and was later separated from it for unknown reasons.
One of the surviving crew members later said that at first, the weapon system operator, who later was drifting in the sea lifelessly, had been within calling distance. Both had confirmed each other that everything was OK.

FINDINGS WITH RESPECT TO THE INDIVIDUAL CREW MEMBERS

The crew member rescued first (Fig.2) was wearing regulation clothes, i.e. the sea survival suit MK 10 and the padded thermal underwear as well as long underclothes underneath and in addition anti-g trousers. He was in good condition when rescured.. He only said that his feet had been cold, but there were no other signs of hypothermia.

In the case of the crew member rescued second, who also had been wearing regulation clothes but no anti-g trousers, the sea survival suit had filled with water up to the hips because the closure plug for the anti-g adapter had been lost. He showed moderate symptoms of hypothermia and was able to talk and walk. The sea survival suit and the hands of this man were covered with tiny metal particles. The X-ray pictures taken afterwards showed that metal particles had penetrated both hands.

The crew member who was rescued third exhibited somewhat more obvious signs of hypothermia; he also was able to talk. In his case, too, the clothes worn were according to the regulations. He was not wearing anti-g trousers and the sea survival suit had also filled with water up to the hips due to the loss of the closure plug of the anti-g adapter. In addition, there were signs of burn on the right sleeve of the life jacket which continued up to the right side of the face where there were surface burns. The signs of burn were probably caused by the jettison system of a canopy damaged during the collision which thus did not separate properly.

The subsequent analysis of the metal particles which were found in the crew member rescued second made it possible to identify them as lead with adhering silicone particles as can be found in the detonating cord of the canopy.

For the time being, the three survivers were not examined any further due to their good conditions.

The medic said that the head of the WSO, who was rescued last and was found drifting in the water lifelessly, had hung down to the right and had been brought into this position by the helmet which he had still been wearing. Sea water had flown into and out of the mouth. The emergency signal he had been

carrying had been hanging deep into the water. As a consequence, the signal had been considerably weaker than those of the others which had probably been the reason why it was picked up last. After the rescue by means of the winch, resuscitation measures were started in the helicopter immediately. These were continued after the rescued crew members had been taken over by an ambulance and during the transport to the hospital in Thistedt. A doctor present in the helicopter reported that the WSO had been dead, at least clinically, at the time he was rescued. The sea survival suit had been cut open already in the helicopter. It turned out that underneath, the WSO had neither worn the padded thermal underwear nor long underclothes. On the whole, the sea survival suit had filled with a normal quantity of water. Already during the transport, attempts were made to resuscitate the WSO by means of defibrillation; he was intubated and given artificial respiration using oxygen. In spite of these efforts, he was pulseless and electrocardio-graphically asystolic when admitted to hospital. There, he was again subjected to defibrillation and given artificial respiration. After about 30 minutes, resuscitation was given up. The measures aimed at warming him up, which had already been begun during transport, had been continued in hospital. They caused the rectal temperature to rise from an initial 28°C (approx. 82 °F) to 29.4 °C (85 °F). In the death certificate, he is described as a strong, relatively young man with rigor and not completely developed livors mortis. No signs of bruises could be found. The endotracheal tube was left in. It was not possible to make water rise in it by applying pressure to the chest. The death certificate states that the death must be considered a consequence of the prolonged exposure to cold water with subsequent strong hypothermia. It says that this led to electrolyte disturbances with cardiac irregularity.

In the course of the external post-mortem examination and autopsy of the dead crew member conducted by our institute, signs of the resuscitation measures carried out in the hospital were found, such as electrodes on the chest, a perfectly circular mark in the middle of the chest which is typical of defibrillation and signs of intubation in the mouth and pharynx. In addition, an about penny-sized, brownish dehydrated part of the skin with a central defect formation on the outside of the right thigh was detected during the external post-mortem examination. On incision, a hemorrhage extending over a length of 23 cm was found which, on the one hand, points to a relatively long survival after ejection but on the other hand was probably very painful and is likely to have limited the weapon system operator's mobility considerably.

Further findings of the post-mortem examination as well as facts with respect to the cause of death will be dealt with later in lecture No. 21.

DISCUSSION

How are the findings to be interpreted and which conclusions can be drawn for practice as far as ejection over the sea is concerned?

PATHOPYSIOLOGY

If ambient temperatures are normal, the heat given off by the body corresponds to the heat produced in the body. Living human beings give off heat from

their body via the air by means of heat radiation, heat conduction, convection and evaporation. The body responds to a decrease in the ambient temperature by increasing heat production and possible trembling caused by cold. In the water, the conditions are somewhat different.

The conducting capacity of water is approximately 25 times higher than that of air which means that the body may reach a critical limit of heat loss even if the water temperature is 20°C (68 °F). In the water, heat is mainly given off by means of heat conduction and convection. Movements in the water lead to an additional increase in heat loss due to convection. In this context, the subcutaneous adipose tissue is also decisive. Thin people chill through more quickly than fat ones, especially if moving. When hypothermia starts, i.e. approximately from a body temperature of 35°C (95 °F), the body responds by increasing metabolism by a factor of up to 20 in order to boost its endogenic heat production, e.g. by means of trembling caused by cold. At a temperature of about 28°C (approx. 82 °F), physical heat regulation fails.

A protective suit's primary function is to protect the body from water and cold. Its insulation capacity depends mainly on the thickness of the layers of clothes and the air trapped in between them. If this air is replaced by water, e.g. due to a leakage when immersed in water, insulation is reduced considerably.

In the literature on this topic, descriptions of all kinds of different trials for testing sea survival suits can be found. Above all, in the study by Anton tests were carried out with clothes comparable to those worn in our case. The test persons stayed in the dinghy with complete winter protective clothing for 4.5 hours. In the first series of tests, the complete winter protective clothing consisting of long underwear, anti-g trousers, thermal underwear, sea survival suit MK 10, boots and waterproof leather gloves was tested. The test persons for the second series of tests were dressed the same way; however, they did not were thermal underwear. The temperature of the esophagus, the rectal temperature and skin temperatures at various places were measured. There were hardly any differences as far as the average temperature of the esophagus was concerned, which was about 37 °C (approx. 99 °F), in both the first and the second series of tests. However, the rectal temperature dropped steadily after a slight rise in the beginning; it decreased more sharply in the series of tests without thermal underwear. However, it did not fall below 36 °C (approx. 97 °F). The skin temperature dropped sharply at first but then only decreased slowly. For test persons without thermal underwear, this decrease was considerably more pronounced.

In our case, the persons concerned had been wearing similar winter protective clothing.

In case no. 1, the clothes were according to the regulations; the crew member was rescued from his dinghy after 1.5 hours; he only complained about cold feet and showed no other signs of hypothermia.

In the cases no. 2 and 3, the clothes were in accordance with the regulations but due to the loss of the closure plug of the anti-g adapter, the survival

suits of both of them had filled with water up to the hip. This penetration of water led to a considerably greater loss of body heat. The crew member rescued third after about 2 hours exhibited clear signs of hypothermia.

In case no. 4, the clothes were not in accordance with the regulations. The WSO had neither worn long underclothes nor thermal underwear. Furthermore, he was not in his lifeboat, at least at the time he was rescued. As the signal was dampened due to the fact that the radio equipment was hanging down into the water, he was rescued last. In a little over 2 hours, i.e. when finding him, his rectal temperature had already dropped to 28°C (approx. 82 °F). The subsequent rise in the rectal temperature to 29.4 °C (85 °F) could be explained as the dissipation of the heat from the core of the body, which, at the beginning, certainly had still been warmer, to the outside. This sharp drop of the rectal temperature may have been caused by the increased loss of heat due to convection in a heavy sea and, in the beginning, perhaps by the crew member's swimming action.

The fatal case shows clearly that complete clothes must be insisted on and that failure to comply with this regulation may lead to a tragical outcome.

In summary, one can say that it has been proved that sufficient protection against hypothermia can be achieved under the mentioned conditions even if the sea is cold if regulation clothes are worn and if the person concerned stays in his dinghy. The clothing laid down in the regulations provides a good chance of survival also in cases of emergency bailout over bodies of water.

The literature will be available at the authors adress.

Weather conditions on the day of the accident

Air temperature	5 - 6°C
Water temperature	11°C
Dew point	6°C
Wave height	4 - 4,5 m
Wave period	8 / s
Wind	150°, 35 kn
Visibility	4 km, haze and broken clouds up to 2000 ft, 10 km above 4000 feet, new moon, starry

Fig.1

Rescue times after collision

Case 1: 1 h 28 min	in the dinghy
Case 2: 1 h 34 min	in the dinghy
Case 3: 2 h 02 min	in the dinghy
Case 4: 2 h 14 min	drifting in the water

Fig.2

Clothing and findings of crew members after the rescue

Case 1: 1 h 28 min	clothing according to regulations, anti-g-trousers, in good condition without signs of hypothermia
Case 2: 1 h 34 min	clothing according to regulations, water in the sea survival suit up to the hips, but in good condition with moderate signs of hypothermia
Case 3: 2 h 02 min	clothing according to regulations, water in the sea survival suit up to the hips, but in good condition with somewhat more obvious signs of hypothermia
Case 4: 2 h 14 min	clothing not according to regulations, not in the dinghy, at the first examination in the helicopter unconscious, rectal temperature 28°C

Fig.3

ADVANCED INTEGRATED COLD PROTECTION FOR AIRCREW.

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SUMMARY.

In this paper the concept of an Advanced Integrated Survival System is introduced and discussed in relation to the Helicopter Crew Member and Passengers, although the principles are equally applicable to many other types of user and circumstances requiring specialised protective clothing.

The fundamental principles behind the concept are firstly that the wearer should be given protection against all of the hazardous responses associated with immersion in cold water and secondly, that the individual components which make up the integrated survival system (ISS) must be compatible and complementary. They may also be interdependent.

DISCUSSION.

The Integrated Survival System represents a radical rethink of the personal survival equipment used in situations where life can be at risk at sea - not only by helicopter crew and passengers, but also by workers on oil rigs, offshore yachtsmen, passengers and crew on ships, fishermen and members of the Armed Services. The philosophy behind the development of an Integrated Survival System was determined by very extensive research work involving experts from the fields of physiology, health and safety and diving medicine.

Existing in-water survival equipment had shortcomings which had been identified by independent testing and research - including the possibility of incompatibility of lifejackets and survival suits (which normally came from different manufacturers and had not been designed to work together) and the probability of inadequate protection from hypothermia and cold shock.

Information on the performance of uninsulated immersion suits had been available since 1956 (Hall & Polte 1956). Figure 1 shows how any leakage dramatically affects the performance of an uninsulated immersion suit - even as little as 500 grams of water leads to a loss of 30% of the insulation value. In rough seas, leakage can and does occur. Plotting the curve of an uninsulated immersion suit, which provides 0.3 CLO, on Figure 2, demonstrates that in cold water, such as in the North Sea, (which goes down to 4°C), predicted survival time is only about 2 hours in calm conditions. Testing in rough water under laboratory conditions has suggested that these projected survival times could be reduced by as much as 30%. (Hayes et al 1985, Tipton, 1991).

Our own tests at CORD in Canada, proved that the CLO value of an uninsulated immersion suit barely meets the minimum acceptable limits of IMO-SOLAS i.e. 0.3 CLO. Our manned trials at the Institute of Naval Medicine, conducted by Robens Institute, demonstrated that in water at 4°C an uninsulated immersion suit allowed a subject to become hypothermic in just 78 minutes with a core temperature falling at a rate of

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

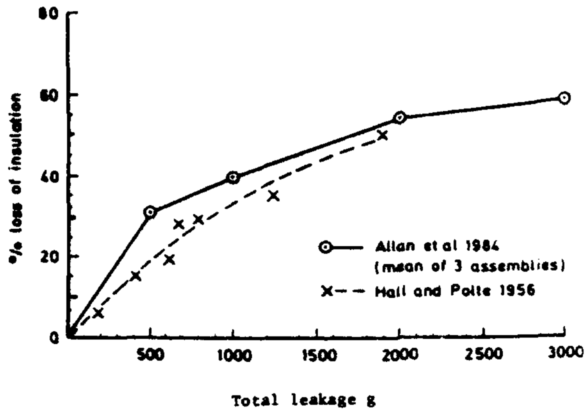
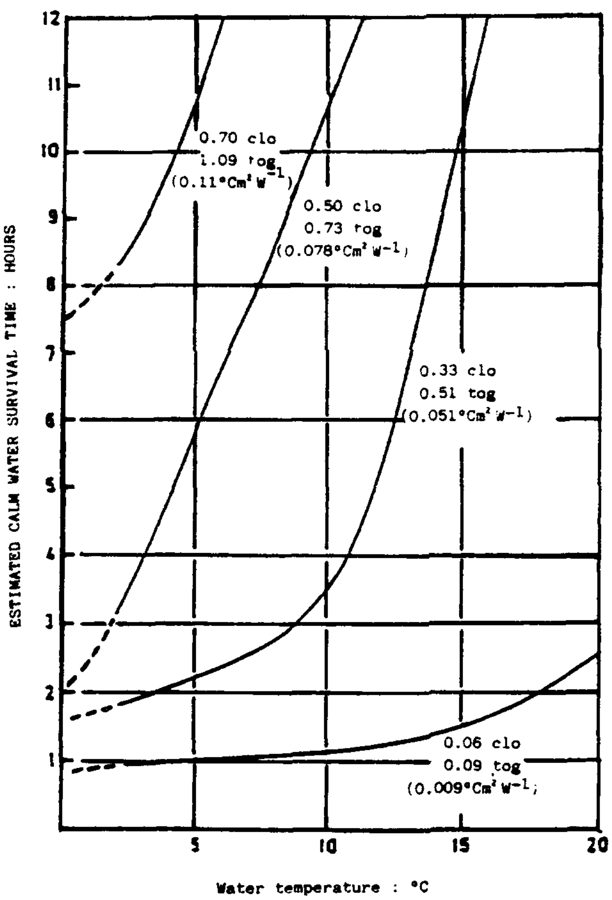


FIG.1 PERCENT LOSS OF INSULATION PLOTTED AGAINST LEAKAGE



PREDICTED SURVIVAL TIME AGAINST SEA TEMPERATURE FOR
FOUR LEVEL OF IMMERSED CLOTHING INSULATION

FIG. 2

NUNNELEY S.A. AND WISSLER E.H., PREDICTION OF IMMERSION HYPOTHERMIA IN MEN WEARING ANTI-EXPOSURE SUITS AND/OR USING LIFE RAFTS. ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT. REPORT NO. AGARD-CP-286, 1980.

1.65°C/hour.

These performance statistics pose serious and fundamental questions about survival suit design. There are clearly many variables in an emergency situation at sea - such as water ingress into the immersion suit, adverse weather, rough seas and time before rescue. The protection afforded by survival equipment against hypothermia should be far in excess of the minimum for survival. Whilst an uninsulated immersion suit is comfortable in air and has a low buoyancy index, it is unlikely to provide adequate protection in cold water. An inherently insulated immersion suit is not a viable alternative particularly for helicopter and aviation applications, because it is not environmentally acceptable in air, and is excessively buoyant, making escape from a submerged craft even more difficult.

However, other physiological problems arising from immersion in cold water have been identified during the ongoing research work of Dr.M. Tipton of Robens Institute which have also had a far reaching effect on our approach to survival suit design. The "cold shock" response includes increased heart rate and the contraction of the blood vessels which together cause blood pressure to rise. In addition reflex gasping and uncontrollable hyperventilation can occur, as a result of which breath-hold times can be so greatly reduced that escape from a submerged craft or upturned helicopter might be impossible. Clearly there is a risk of aspirating water and drowning can occur. Only when "cold shock" has been survived does the longer term problem of hypothermia become a factor in survival.

Another potential physiological problem to be considered is hydrostatic squeeze, which occurs when the immersed survivor floats with his legs vertically below him and hydrostatic pressure pushes blood from the lower limbs into the upper torso. If, during the rescue, he is lifted from the sea vertically, the hydrostatic pressure is removed and gravity is reintroduced. As a consequence cardiac output can fall and arterial pressure collapse.

Although still at risk when being lifted from the water vertically, a survivor who has been floating horizontally at the surface of the sea is at less risk of post immersion collapse than a survivor who has been floating vertically in the water for a corresponding period of time.

In all rescues from the sea it is preferable that the survivor be lifted horizontally whatever his attitude in the sea. (Golden, Hervey and Tipton, 1992).

The Integrated Survival System has been designed to provide equipment which:

(a) Is compatible and complementary.

(b) Comprehensively addresses all of the physiological hazards experienced by the immersion victim.

The component parts are:

1. An emergency underwater breathing device which is safe and easy to use, to combat the effects of cold shock and facilitate escape from a downed flooded helicopter.

2. A lifejacket which combines high buoyancy with reliable self righting capabilities when wearing a survival suit.

3. A survival suit which provides advanced protection from hypothermia, yet be comfortable in air, meeting environmental

and low buoyancy requirements when flying yet giving a high insulation value, and horizontal flotation in water.

The first element of the system has to address the immediate problems of the immersion victim who is in the first moments of a helicopter accident. Helicopters are top heavy and therefore invert. In the ensuing in-rush of cold water, the victim is disoriented both by the inversion of the helicopter and the poor visibility, giving rise to confusion and panic. To make matters worse, "cold shock" takes hold and his breath-hold time is drastically reduced. This is an extremely hazardous situation and an Emergency Underwater Breathing Device could make the vital difference between escaping and becoming a fatality.

Emergency Underwater Breathing Devices are in existence, mainly provided by the Armed Services for its personnel (for example HEED II in the U.S. and Canada, STASS for the Royal Navy, and HEED I, used by the U.S. Coastguard). These devices have distinct disadvantages:-

1. The risk of pulmonary overpressure accident - the open circuit systems can be breathed down due to hyperventilation, and duration times as low as 15 seconds have been recorded from what are theoretically 3 minute sets.

2. Considerable maintenance is needed to ensure that the sets are full and in working order during potentially long periods of storage.

3. Rigorous training requirements to overcome the dangers of misuse, with pool training requiring a recompression chamber and medical staff in attendance in case of pulmonary overpressure accidents.

4. With HEED I, the emergency breathing system is built into a lifejacket, which has one compartment inflated by O_2 - but this is excessively buoyant and would inhibit escape from the helicopter. In addition, the devices which utilize high pressure gas cylinders are permitted in Military aircraft but contravene Civilian regulations and cannot be used in the wider context of helicopter operations.

The criteria for our "Air Pocket" Emergency Underwater Breathing Device, is that it is simple in design and, when used as recommended, can only be of assistance in extending the underwater survival time of the user. Because it is used unprimed, the user only rebreathes the volume of air in the lung on submersion, thus avoiding the risk of a pulmonary overpressure accident.

Air Pocket is basically a counterlung integrated into the Survival Suit but is not physically part of the suit itself. It is placed as near to the lung centroid position as possible and is designed so it can be breathed in any attitude underwater within prescribed acceptable breathing limits.

The Air Pocket has a breathing hose, swivel connectors and mouthpiece, and is mounted so that it is accessible and easy to use, whilst offering no encumbrance to the immersion victim. The mouthpiece is placed in the mouth when assuming the crash position. It is breathed to atmosphere as long as possible - then, after taking a deep breath, the user changes over to the Air Pocket counterlung. It is recommended, but not essential, to hold one's breath as long as

SURVIVAL SUIT PERFORMANCE CHART

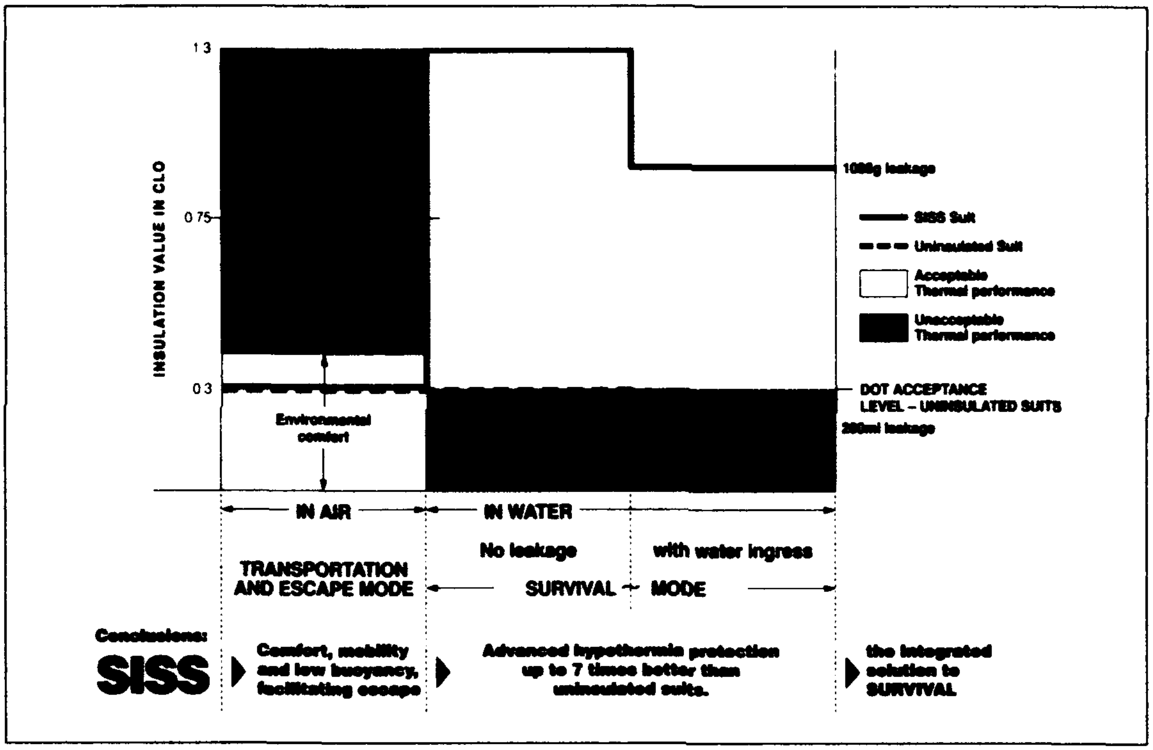


FIG. 3

possible. Trials in 10°C water have shown the average breath-hold time in active mode to be 17 seconds. Once breath-hold is broken, the user breathes on the Air Pocket until he has made his escape.

Air Pocket is a safe and effective Emergency Underwater Breathing Device requiring very little maintenance and for which the training requirement is uncomplicated and without risk.

Our research and testing has conclusively shown that a survival suit should be designed to reduce the "cold shock" response. When this is done Air Pocket's performance is enhanced - in other words, the Air Pocket is best used as part of an Integrated Survival System.

The second element of the Integrated System is the lifejacket and we decided to depart from traditional lifejacket configurations and design an asymmetric lifejacket which offered the greatest possible turning moment, ensuring that the resistance created by the survival suit could be overcome and the survivor self righted. The asymmetric lifejacket has a high buoyancy (275 Newtons), it has a low profile when deflated, but on inflation the asymmetric shape gives a mouth above water height in excess of 150mm and because of the shape of the asymmetric lifejacket no water is channelled into the survivors mouth. The splash guard is designed for ease of deployment ensuring that there is no $CO2$ build up or splashes at the survivors airways. Several versions of the lifejacket are available - manually operated versions for transit use and automatically operated versions for abandonment at sea.

A further advantage of the Integrated Survival System can be considered at this point. Where survival suits are constructed in flame retardant materials such as Nomex III and subjected to flame manikin tests such as those carried out at British Textile Technology Group in combination with traditional lifejackets, made and supplied by other manufacturers, the lifejackets invariably cause secondary burning. Because we are committed to the concept of an integrated system, manufactured as a group of compatible complimentary components, we have allowed for the total system including the lifejacket, to be flame retardant, and can even meet an Index A rating to British Standards 6249. The Integrated Survival System recorded no pain or burn at 1000°C for a period of 7½ seconds during testing at British Textile Technology Group.

The final element of the Integrated System is the Survival Suit itself, which was designed in the light of the background research detailed at the beginning of this paper. The requirement was for comfort, mobility and virtually no thermal capacity in air, but a high level of thermal performance (at least 0.7 CLO) in water, to provide advanced protection from hypothermia over extended periods of time. To meet these conflicting requirements it was necessary to design a variable volume suit, which is inflated by the wearer, using CO_2 gas, with the gas interlayer expanding in parallel so that no "cold spots" are formed and no direct cold transfer can occur. CO_2 gas has excellent thermal properties and is convenient to store and to use. The inflation of the suit also had the benefit of maintaining the survivor in a stable, horizontal position in the water, improving thermal performance and minimising the dangers of hydrostatic squeeze. In fact, the survival system when fully deployed can be described as being like a "personal liferaft" - the wearer is protected from wind, waves and the onset of hypothermia. Furthermore, any

ingress of water will not significantly affect the performance of the inflated suit due to the waterproof nature of its inherent insulation.

The thermal performance graph (Fig.3) shows the performance of the S.I.S.S. in its dual modes (deflated in air, inflated in water) against that of an uninsulated dry suit.

CONCLUSION.

The Shark Integrated Survival System is probably the first in-water personal survival system to embody the concept of integration, i.e. equipment which is compatible and complimentary, designed and engineered to maximize the survival prospects of the user. As such it comprehensively addresses all of the physiological responses experienced by the immersion victim, including "cold shock" and hypothermia and dramatically enhances his ability to escape and survive an emergency at sea.

The concept of the Integrated Survival System has been developed and refined, first for the helicopter passenger, and secondly for the offshore yachtsman. The SISSTEMAIR version of the Shark Integrated Survival System won two major awards during 1992, the IMTEC Innovation Award and the Silk Cut Nautical Award. Our Design Team are currently working on an Integrated Survival System for Aircrew. Flight Trials on North Sea Helicopters are being carried out and Yachtsmen are already sailing around the world using the Shark Integrated Survival System.

NOTES.

The Integrated Survival System has been developed as part of the Shell and Esso Exploration and Production Limited "Survival in the Sea" Project. We gratefully acknowledge their sponsorship of the development work.

The Shark Integrated Survival System and Air Pocket are covered by Worldwide Patents.

Shark Group are a Civil Aviation Authority Prime Contractor for Design and Manufacture and have C.A.A. and D.O.T. Approvals for their products.

ACKNOWLEDGEMENTS.

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EMERGENCY UNDERWATER BREATHING AIDS FOR HELICOPTER PASSENGERS AND CREW

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SUMMARY

In this paper the rationale for the provision of some form of helicopter emergency underwater breathing aid (HEUBA) for helicopter passengers and crew is briefly discussed and the thoughts and work which resulted in the production of a new aid, "Air Pocket", is reviewed.

THE RATIONALE FOR HEUBA

There is still reluctance in some quarters to provide helicopter passengers and crew at risk of immersion in cold water with some form of HEUBA. This reluctance is due to many factors, one of which is a lack of understanding of the risks to be faced by an immersion victim. Hypothermia is generally thought to be the major risk and the design of immersion suits, claims for their performance, the tests and standards used to evaluate them and policies for their use are all still primarily influenced by this belief.

Despite the vast amount of attention which has been given to hypothermia and the efforts which have been made to protect against it, anecdotal, statistical and experimental evidence[1-5] suggest that the initial responses to cold water immersion can present a significant threat to life during the first minutes of immersion. These responses have been given the generic title of the "cold shock" response; they are thought to be initiated by a sudden fall in skin temperature and can result in tachycardia, hypertension, an inspiratory `gasp' response and uncontrollable hyperventilation[5,6,7,8].

These responses constitute a serious threat to immersion victims, particularly those with pre-existing hypertension or heart disease, or those who need to consciously suppress their breathing following immersion in choppy water or submersion in a sinking craft. Results[9,10] have revealed that immersion in water at a temperature of between 5 and 10°C can reduce the average maximum breath hold time of normally clothed individuals from about 50 seconds in air to 10 seconds underwater, with some individuals finding it impossible to breath hold at all.

Wearing an immersion "dry" suit with underclothing increases average maximum underwater breath hold time to approximately 30 seconds at rest and 17 seconds during exercise. Again, however, even with this level of protection, the maximum breath hold time of some individuals is less than 10 seconds[11].

The cold-induced reduction in maximum breath hold time, is clearly a potentially hazardous response for helicopter passengers and crew. The likelihood of a helicopter inverting following ditching is high; it has been reported[12] that in 47% of Royal Navy helicopter accidents between 1972-1984, the helicopter sank or inverted immediately on arriving at the surface of the water. Thus, there is a reasonably high chance that the passengers and crew of a ditched helicopter will have to perform an underwater escape.

It is impossible to determine a single time required for successful underwater escape; the "best" estimates from informed bodies such as the military, coastguard and civilian operators within the oil industry suggest that the time required is between 40 and 60 seconds. It is the short-fall between this time and that which can be achieved in cold water by breath holding alone, which forms the basis of the rationale for HEUBA.

CONSIDERATIONS IN THE SELECTION OF AN HEUBA

It seems likely that many of those who advocate the use of commercially available HEUBA have not fully considered the implications associated with their introduction. Among the questions which should be considered before bringing such equipment into service are:

1. Does their use present new dangers to the escapee?

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

With regard to helicopter passengers these dangers might include: increased buoyancy; snagging hazards; problems clearing water from the regulator and mouthpiece; pulmonary over-pressure accidents leading to gas embolism of the brain. Current commercially available HEUBA require additional pressurised air to be breathed beneath the water. The use of such air at depth introduces the possibility of a pulmonary over-pressure accident. This can occur if an individual inhales from a gas supply at a depth as shallow as 3 metres and then holds his breath as he rises to the surface of the water[13].

2. What are the training implications associated with the introduction of such equipment? If the equipment is complex, how long will it take to train individuals in its use? What precautions will need to be taken during training, for example will medical attendants and recompression facilities be required? These are particular problems for some of the potential civilian users within, for example the oil industry, who may have large numbers of passengers to train.

3. Unit and maintenance costs.

Consideration of such questions helps in the production of a specification for the "ideal" HEUBA:

> "a HEUBA should significantly extend underwater survival time when compared with maximum breath hold time. It's use should not introduce any additional dangers. It should be simple to use, thereby reducing the training time and the complexity of actions required in the emergency situation".

AN ALTERNATIVE HEUBA

In theory, this specification can be met by a simple device comprising a plastic bag connected to a mouthpiece. Provided the bag is empty on submersion it will be impossible for it to provide a pressurised supply of air when taken to depth. This eliminates the primary cause of pulmonary over-pressure accidents. The system can extend underwater survival time by enabling the user to capture and rebreathe his exhaled breath after maximum breath holding.

Such a system relies on the fact that whilst alterations in arterial gas concentration can influence maximum breath hold time, it is actually limited by afferent information arising in the lung[14]. These afferents, which are thought to arise in the chest wall[15], can be attenuated and, as a consequence, maximum breath hold time can be extended by various manoeuvres including: swallowing; an isovolumetric movement of the rib cage; rebreathing[16]. With regard to rebreathing, it has been known for many years[17,18] that the time an individual can spend without fresh air can be significantly extended beyond maximum breath hold time by this procedure.

The Robens Institute in conjunction with a manufacturer (Shark Group of Companies Ltd) has been developing and testing a simple HEUBA, called "Air Pocket", which has been designed with the information presented above in mind. In practice, consideration has to be given to: hydrostatic imbalance; breathing resistance and a method of recapturing exhaled air, no matter to where it migrates in the bag on submersion. Thus, Air Pocket is, inevitably, a little more complex than a plastic bag connected to a mouthpiece.

EVALUATION OF AIR POCKET

The development of "Air Pocket" has included static and dynamic unmanned trials using a head and torso breathing manikin[19], and manned tests in air and warm water[20]. In these investigations the concept of providing a simple rebreather was evaluated, its design and fit finalised and method of use established. The final design comprises: a 12 litre bag with an internal system for ensuring the retrieval of exhaled air, respiratory tubing and a mouthpiece. The mouthpiece incorporates a simple, manually operated, valve which enables the user to switch from breathing ambient air to rebreathing.

Tests[20] have shown that, with regard to total time on Air Pocket, it makes no difference whether users rebreathe immediately or breath hold maximally before rebreathing. It was decided to advise individuals to breath hold before using Air Pocket as this would ensure that Air Pocket could only be of assistance; those who use it during a real accident would presumably have otherwise drowned. Experimentation with the volume of the final inhalation before using Air Pocket showed that, particularly in water, a small inhalation was preferable to a large one with regard to the ease with which Air Pocket could subsequently be used. At any lung volume Air Pocket extended the time subjects could spend without fresh air when compared to breath holding.

The experiments described below are those in which Air Pocket was evaluated in cold water.

EVALUATION OF AIR POCKET IN COLD WATER

The experiments were undertaken at the Royal Navy's (Institute of Naval Medicine) immersion facility, based at RN Establishment Seafield Park, Hillhead, Hampshire, UK.

METHODS

Eight healthy males volunteered to act as subjects for the experiments. Each gave his written informed consent to participate in the presence of an independent witness. The protocol for the experiments had been previously approved by the ethical committees of both the Royal Navy and Surrey University.

An Independent Medical Officer performed medical examinations on the volunteers and was in attendance during all of the experiments. During the submersions the subjects were closely attended by two safety swimmers.

Experiment 1: seated submersion

Each subject undertook two upright, seated submersions: the first into stirred water at 25.6°C (SD 1.5) and the second into stirred water at 9.9°C (SD 0.3) The colder water temperature was chosen to represent the average temperature of the water around the UK.

For each experiment the subjects were dressed in thermal underwear, woollen socks, woollen polo-necked pullover and an appropriately sized immersion "dry" suit (Shell Integrated Survival System [SISS]), into which Air Pocket had been configured. During all immersion work the SISS was worn fully donned - hood up, wrist seals and zip secured. A nose-clip was worn throughout each submersion, goggles were not provided.

Before their first submersion in warm water, each of the subjects spent some time in air and water being trained in the use of Air Pocket, and being familiarised with the experimental procedure. As part of the training, the subjects were instructed to take a slightly larger than normal breath in before activating the mouthpiece mechanism which switched them from breathing ambient air to rebreathing from the otherwise empty Air Pocket. This valve was activated by pulling a small "O" ring located on the mouthpiece assembly. The subjects did this just before their airways were submerged. They were also told to perform a maximum breath hold before using Air Pocket.

Only one subject was immersed at a time. Both the warm and cold water experiments began with the subjects sitting in air over the water. When they indicated that they were ready, the chair was lowered at 0.2 $m.s^{-1}$ using an electric winch, until they were just totally submerged. The subjects assumed a standardised posture during the immersions: they held the latch of the seat belt which secured them to the chair with their right hand and the base of the chair, between their legs, with their left hand.

The subjects attempted to remain seated beneath the surface of the water for a maximum of 70 seconds; this time was fixed as the ethical withdrawal criterion on the basis of the results obtained during earlier phases of the project in which carbon dioxide and oxygen concentrations within Air Pocket were recorded during rebreathing at rest in air[20]. The subjects could abort the experiment at any time by either: raising a hand - on this signal the chair on which they were sitting was winched out of the water; or by releasing the seat belt and standing up.

During the submersions the subjects indicated when they took their first breath in after maximum breath holding by raising their right arm.

Experiment 2: simple simulated helicopter underwater escape

The same eight subjects undertook two further submersions: the first into stirred water at 22.3°C (SD 0.2) and the second into stirred water at 10.1°C (SD 0.2). For each experiment the subjects were dressed as described above. As the subjects had completed Experiment 1, no familiarisation runs were permitted before the present experiments. As with Experiment 1 however the subjects undertook the warm water immersion first.

Only one subject was immersed at a time. Both the warm and cold water experiments began with the subjects sitting in air over the water. When the subjects were ready they took a slightly larger than normal breath in and activated the mouthpiece valve which switched them from breathing ambient air to rebreathing from the otherwise empty Air Pocket. Activating the valve was the signal for the safety swimmers to rotate the chair on which the subjects were sitting by 180 degrees. This resulted in the subjects "rolling" into the water to an inverted position. Whilst on the chair the subjects assumed the same standardised posture described for Experiment 1.

Immediately after reaching the inverted position the subjects were required to locate a ladder which was fixed to the floor of the pool. When they had a firm grip on the ladder they released the latch of their seat belt and began to move, hand over hand, back and forth along the ladder at a steady and continuous rate (a minimum of 4 traverses) for as long as they could.

The ladder along which the subjects exercised was 3 metres long, it was marked by luminescent paint and helicopter underwater emergency lighting, and fixed at a depth of 1.5 metr . This depth was based on an analysis of the depth required to perform an underwater escape from an inverted, floating

helicopter.

The maximum time subjects were allowed to spend underwater during these experiments was ten seconds shorter at 60 seconds; this time was determined from the findings of earlier experiments in which the carbon dioxide and oxygen concentrations within Air Pocket were measured during rebreathing whilst exercising in air[20]. The subjects could abort the experiments at any time by either: raising a hand when seated on the chair - on this signal the chair was returned to the upright position; or by letting go of the ladder and standing up.

As with Experiment 1, subjects were instructed to hold their breath for as long as possible before using Air Pocket. The subjects indicated when they took their first breath in after maximum breath holding by raising their right arm.

Experimental measures

All submersions were recorded on an underwater video from which maximum breath hold time was obtained from the indication given by the subjects. This time was substantiated by the observations made by the safety swimmers. Timings were all recorded on a custom made split timer unit. Total underwater time was taken from when the mouth was submerged to when it re-appeared above the surface of the water.

3-lead electrocardiography was undertaken by telemetry during each submersion as part of the medical cover given to the subjects.

RESULTS

Experiment 1

During the experiments in warm water four of the eight subjects managed to hold their breath for the 70 seconds of the experiment, they did not therefore use Air Pocket. However, the other four subjects, even in warm water, needed to use Air Pocket in order to remain submerged for 70 seconds.

In cold water, Air Pocket was used by all of the subjects and significantly extended the time they were able to remain submerged. Indeed, 7 of the 8 subjects reached the withdrawal criterion of 70 seconds by using Air Pocket; included amongst these subjects was one whose maximum breath hold time had only been 6.1 seconds (No. 7). The maximum breath hold time (BHTmax), the time spent rebreathing with Air Pocket (rebreathe time, RBT) and the total time each subject spent underwater are presented in Figure 1. The total time spent underwater is represented by the sum of BHTmax and RBT.

Experiment 2

In warm water, all of the subjects managed to remain submerged for the maximum permitted time of 60 seconds although all had to use Air Pocket in order to do so.

In cold water, Air Pocket was used by all of the subjects and significantly extended the time they were able to remain submerged. Indeed, 5 of the 8 subjects reached the withdrawal criterion of 60 seconds; included amongst these was one subject whose BHTmax was only 9.2 seconds (No. 7). The BHTmax, RBT and total time each subject spent underwater are presented in Figure 2.

EVALUATION DURING SIMULATED HELICOPTER ESCAPE

In a subsequent set of experiments the performance of Air Pocket was evaluated during much more realistic helicopter underwater escapes. These experiments were undertaken at Survival Systems Ltd, Dartmouth, Nova Scotia, Canada, in their Modular Egress Training Simulator (METS). The aim of the experiments was to assess whether the use of Air Pocket introduced any problems associated with manoeuvrability. No such problems were identified[21].

DISCUSSION

The average BHTmax of subjects during the cold water immersions of Experiment 1 was 30.4 seconds, this figure agrees well with those which have been reported previously for subjects performing submersions in cold water whilst wearing immersion "dry" suits[9,10]. The average BHTmax of subjects during simulated simple helicopter underwater escape in cold water (Experiment 2) was just 17.2 seconds. The variation between the BHTmax of individuals was also much less than that seen during the resting submersions in cold water. It is clear therefore, that exercise acted as a factor in the determination of BHTmax in the present investigation. However, as indicated by the shorter BHTmax in the cold compared to warm water immersions, cold remained a factor.

The average BHTmax of 17.2 seconds has important implications for those determining the survival equipment necessary for individuals at risk of forced submersion in cold water, and provides further evidence for the requirement for some form of HEUBA for helicopter passengers and crew.

It is clear from the results that Air Pocket significantly extended the time all of the subjects could spend under cold water when compared to their BHTmax. It is not possible to calculate the exact extent of the improvement in underwater survival time provided by

Air Pocket in the present experiments, as the majority of subjects reached the withdrawal criteria and were removed from the water whilst still rebreathing. In the subjects whose maximum time underwater was recorded (Experiment 2, Nos. 2, 6, 7), comparison with their BHTmax shows that the ability to rebreathe using Air Pocket after a maximum breath hold, extended the average time spent underwater by a factor of approximately 2.5. This figure is comparable to those reported from previous work in which rebreathing times have been compared with maximum breath hold times[18,20].

In figure 3 the percentage of subjects able to remain submerged for any given time when breath holding or using Air Pocket is presented. This figure is based on the findings of Experiment 2. It should be noted, that although the withdrawal criterion used in this experiment (60 s) had no consequences for the BHTmax of individuals, all of which were shorter than the criterion, it did prevent Air Pocket demonstrating its full potential as subjects were removed from the water whilst still rebreathing.

Whilst figure 3 should not be regarded as definitive or predictive, it does provide a useful indication of the relative benefit to be gained by the provision of Air Pocket. Most notably, in the conditions of Experiment 2, none of the subjects would have survived 30 seconds by breath holding alone but all would have survived with the use of Air Pocket. Figure 3 further shows that for 100% of subjects to make a successful simple simulated helicopter underwater escape in 10°C water, some would have to have reached the surface within approximately 10 seconds if breath holding. The corresponding time for the same subjects using Air Pocket is approximately 35 seconds.

With regard to the problems experienced whilst using Air Pocket, one subject had a difficult transition from breath holding to using Air Pocket. This was due to the fact that he had over-extended himself by breath holding to his absolute limit - this problem could be removed by instructing individuals not to over-extend themselves when breath holding.

Two subjects complained that they emptied Air Pocket on inspiration towards the end of their submersions. This was coupled with the gradual build-up of a sensation of breathlessness. This latter response is regarded as being of benefit, in that it gives some indication that useful time on Air Pocket is ending. The emptying of Air Pocket on inspiration was probably due to a combination of three factors: i. The subject did not take a large enough breath in just prior to submersion. ii. As individuals run short of oxygen an inspiratory shift in end-expiratory lung volume occurs. This is one of the responses to immersion in cold water[6,22] and was observed during the Air Pocket trials in air[20]. iii. In some orientations, it is possible for Air Pocket to be at a slightly greater pressure (depth) than lung centroid pressure, this results in positive pressure breathing. If the user does not increase expiratory effort slightly to compensate for the small imbalance, then it is possible for inspiration to exceed expiration and, over several respiratory cycles, for Air Pocket to gradually empty and the lung to shift to a higher end-expiratory volume.

None of these factors present insurmountable problems; they can be minimised by correct training and by ensuring that Air Pocket is only used as part of an integrated survival system, included in which should be a good quality "dry" immersion suit. This will reduce the demands placed on Air Pocket and attenuate the cold-induced inspiratory shift in lung volume.

CONCLUSIONS & RECOMMENDATIONS

It is concluded that some form of HEUBA should be provided for helicopter passengers and crew at risk of accidental immersion in cold water. Where there are concerns associated with training requirements, cost and the introduction of additional potential dangers, a simple HEUBA, Air Pocket, exists which can significantly extend the underwater survival time of individuals when compared with maximum breath holding.

It would be totally incorrect, not to say hazardous, for it to be assumed that the performance achieved by Air Pocket in the experiments described above would be repeated if it were used in different circumstances. It is therefore recommended that Air Pocket only be worn with a good quality immersion suit.

It is critical that the different pieces of protective equipment provided for individuals at risk of accidental immersion in cold water, such as an immersion suit, lifejacket and HEUBA should be compatible and complementary. That is, they should be tested and shown to constitute an "integrated survival system"[23], the different components of which may also be interdependent. This is particularly the case with a HEUBA, where the demands made of it will be directly related to the performance of the immersion suit with which it is worn.

Work is underway to develop an enclosed respiratory system, based on Air Pocket, in which exhaled air will react with a suitable chemical substrate to liberate oxygen whilst removing carbon dioxide and water vapour.

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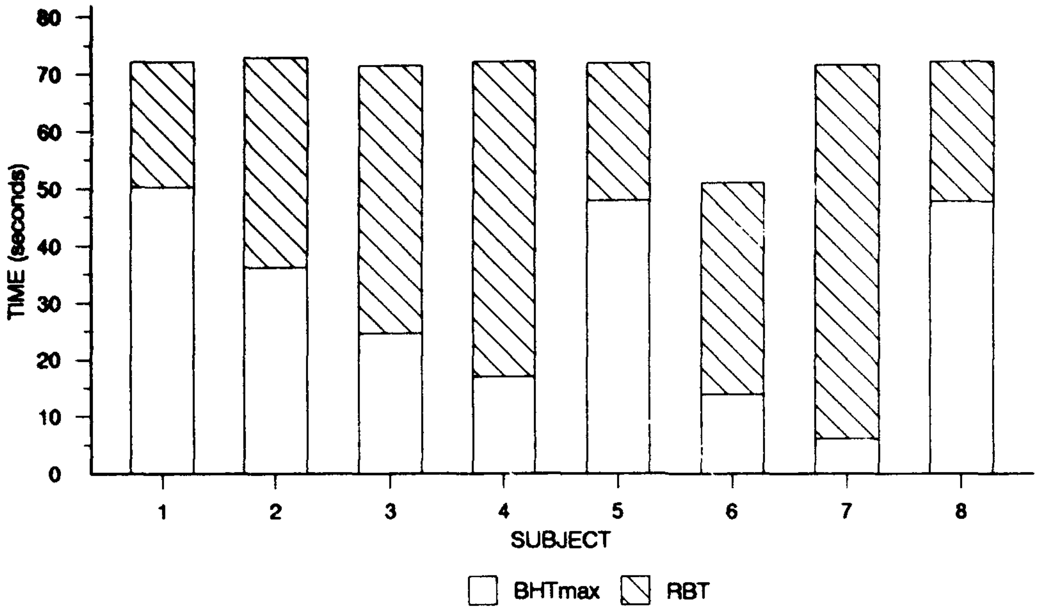
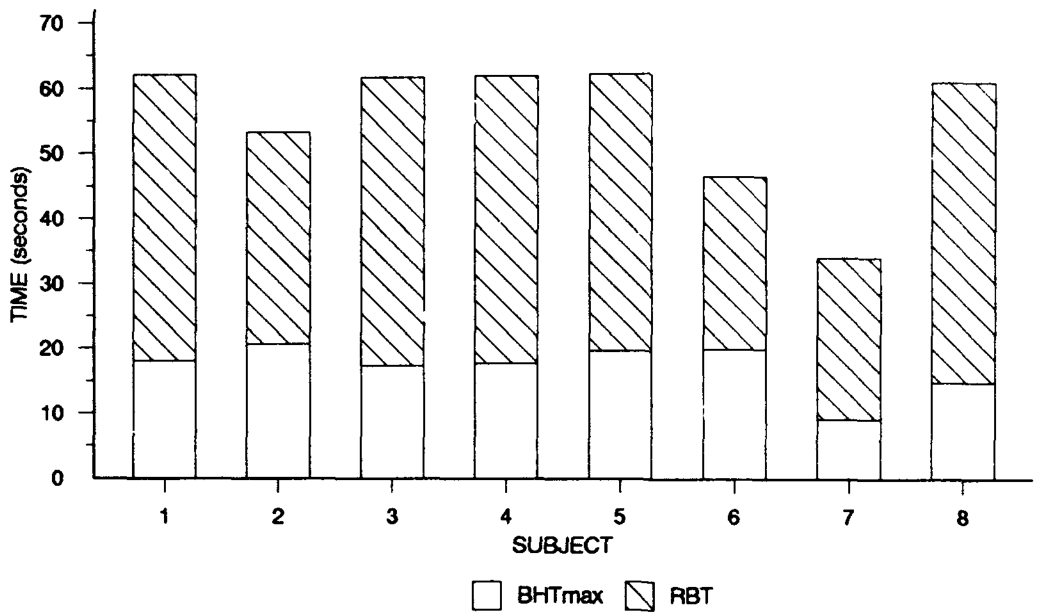


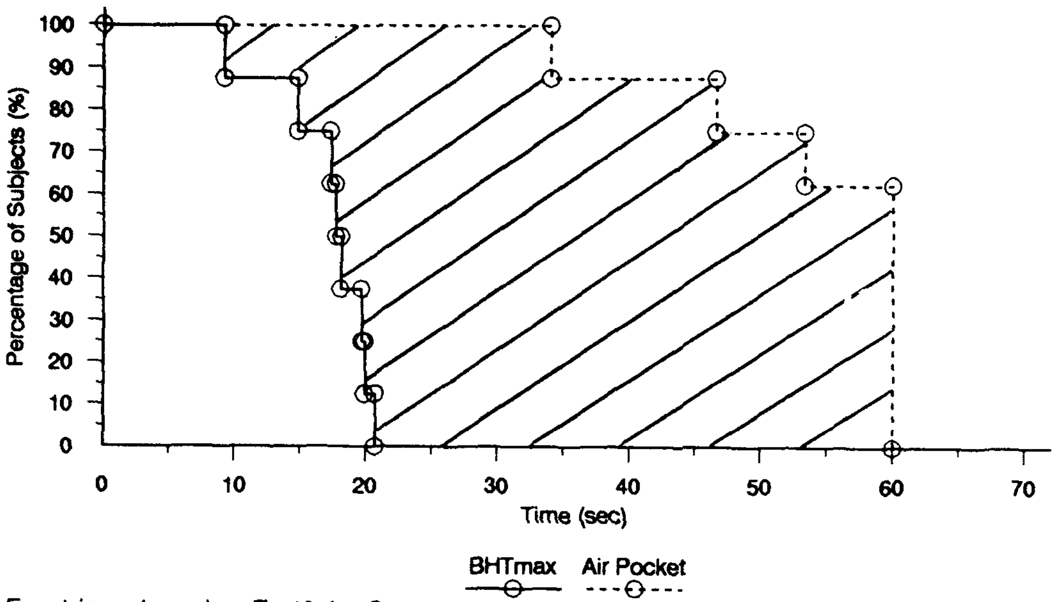
Withdrawal criterion = 70s
AP worn with a "dry" suit (SISS)

Fig 1. Maximum breath hold time (BHTmax) rebreathe time (RBT) and total time spent under 10 deg C water using Air Pocket at rest



Withdrawal criterion = 60s
AP worn with a "dry" suit (SISS)

Fig 2. Max. breath hold time (BHTmax) rebreathe time (RBT) and total time spent under 10 deg C water during a simulated helicopter escape



Exercising submersions Tw 10 deg.C
Withdrawal criterion = 60 seconds
Air Pocket worn with a "dry" suit (SISS)

Fig 3. The percentage of subjects able to remain submerged for any given time when breath holding (BHTmax) or using Air Pocket (n=8)

THERMOREGULATION IN THE EXTREME COLD ENVIRONMENT

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SUMMARY

Thermoregulation is normally viewed as the physiological responses aimed towards keeping the deep body temperature constant and high. For this work this viewpoint is changed, and the human thermoregulation is viewed as those physiological mechanisms that keep the body at an optimal functional state. Here, the extremities and their thermal state is of the highest importance. In the extremities, the arteriovenous anastomoses (AVAs) determine the local temperatures, and by their action also define the thermoregulatory state of the body. The AVAs are centrally regulated, they determine the heat exchange with the environment, they are the main determinants of the average skin temperature. By following their reactions, man's thermoregulatory state can be ascertained. In the treatment of as well hypo- as hyperthermia, these functions are highly relevant. The role of the AVAs place them as a specific thermoregulatory organ responsible for the maintenance of optimal extremity temperatures.

OPTIMAL FUNCTIONING IN COLD

For any work in a cold climate, in the survival situation, maintenance of a high degree of manual dexterity is a must. When threatened by cold, the cooling of hands and feet sets the limit for human endurance. When hands (and feet) are bitterly cold the limits are reached, and if no rewarming is possible cold injury will result. In a survival situation life is threatened.

Manual dexterity shows a linear decrease with falling tissue temperatures. At a tissue temperature around 20 dg.C nervous conduction velocity is halved. Neuromuscular transmission is prolonged. At a local temperature around 7 dg.C the peripheral motor and sensory nerves are blocked (1). Joints and muscles tend to be stiff.

Optimal physiological functioning thus depends on keeping the local temperatures in the extremities high. For most warm-blooded animals this means a local temperature around 35-38 dg.C. The author has measured extremity temperatures in the polar bear, the arctic fox, the hare, the musk ox and the common greenlandic sledgedog. All these Arctic animals have very high extremity temperatures, even at extremely low environmental temperatures. In sledge dogs sleeping at -40 dg.C, the temperatures of the paws, measured between the pads, were above 35 dg.C. This of cause is obvious. In nature, survival of the predator as well as its prey is dependant on their ability to move fast and efficiently, i.e. to maintain high extremity temperatures. In litterature, a counter-current heat exchange between arteries and veins of a cold exposed extremity has been proposed (2) as a means of diminishing total heat loss to the environment. The author's studies do not confirm this theory, which would mean that the extremity temperatures of a cold exposed animal should be low.

To maintain manual dexterity the temperature of the hand and fingers should not fall far below 15 degrees. But it should not be forgotten, that the main muscles of the hand and their proprioceptors are placed up along the forearm, where the temperatures normally will be much higher due to the insulation of clothing. Thus in a survival situation man will be able to work even with hands and fingers close to freezing point.

In man, the local temperatures in arms and legs may fall to such low levels that complete physical impairment is the result. This may occur in a situation where the deep body temperature might still be high, and hypothermia only slight. In the wet-cold situation, as is very often the case in the wet Arctic summer, this may lead to the feared wet-cold syndrome, cold exhaustion (1). In many of these cases, the subject may reason and talk to his followers even at a time, when he is physically helpless.

LOCAL THERMOREGULATION IN HANDS (AND FEET)

The local temperatures in hands (and feet) are determined by the balance between heat produced or brought with the blood to the part and heat lost to the environment. Hands and feet follow in all reactions each other very closely, so further on, only hands will be mentioned, although the same reactions also occur in the feet.

In the hands, local heat production is only of minor importance, heat is almost exclusively brought to the hand and its fingers with the arterial blood. In man's reactions to cold, changes in local blood flow thus determine his possibilities for optimal functioning.

When man is warm, i.e. when his deep body temperature is normal or above normal, his blood flow to the hands will be large. In this situation, the hands are almost the

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warmest areas of the skin surface. The veins on the back of the hand are seen as filled with blood, and the fingertips will typically be the warmest part of the extremity. These warm hands are typical of the hard-working man, even at very low environmental temperatures. He might maintain full dexterity and will be able to perform even very delicate jobs, if the skin is protected against sticking to cold surfaces.

In cold man, i.e. when the deep body temperature is below normal, even in a situation where visible shivering might not be present, the hands will exhibit falling temperatures. If the hands are well insulated, this fall in temperature may be slow, but it is inevitable, and the local temperature will eventually reach that of the environment. In the extreme cold environment, cold injuries will occur.

Normally, man will be aware of this cooling when the local skin temperature of the hand falls below 15 dg.C. But it should not be forgotten, that there is a complete sensory loss at +7 dg.C, and thus even a deep frostbite may not be recognized by the victim. The last sensation he had was - that he did not feel anything! Only the loss of function indicates the severity of the situation.

Even in extreme cold, man will tend to keep his hands passively warm by sticking them in his pockets, where they will be kept at a relatively high temperature. In many work situations in cold, this kind of passive heating of the hands is the only practical way of maintaining sufficient function. This is especially the case in situations where the total physical workload is low, and where metabolic heat production is low. In such situations, the only possible solution is to create a mini work-environment by the use of air heaters etc, where hands, tools and part worked upon are kept warm.
In this situation the limiting factor may be the amount of cold shivering and not local skin temperature.

THE ROLE OF THE ARTERIOVENOUS ANASTOMOSES

When the fingers are the warmest part of the hand in a warm, albeit cold exposed person, and the fingertips are warmest, although the volume to surface ratio would suggest a very high heat loss to the environment, this calls for a special vascular arrangement in the hands (and feet). In the extremities of all warm-blooded animals, including man, arteriovenous anastomoses (AVAs) are found in the most distal parts of the extremities.

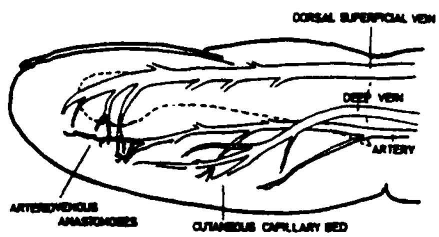
The arteriovenous anastomoses are small vascular vessels with a size closely resembling that of the smaller arterioles, with an inner diameter of 20-100 microns. They have a thick muscular wall, with some specific cells (Hoyer cells) only found in the AVAs. Due to their histological structure, the AVAs presumably act as on-off vessels. Either are they open, or they are closed. This can be demonstrated in the rabbit ear, where the AVA function can be directly followed. As anastomoses, they connect the smaller arteries with the veins, thus bypassing the nutritive vascular bed with its arterioles, capillaries and venoles (3). The AVAs are abundant in the finger tips, and under the nail bed. Their number decreases proximally along the finger, where they are all situated on the volar side. Smaller groups are found in the skin above the thenar and hypothenar muscle groups in the palm of the hands. Proximally to the wrist there are no AVAs. In the feet, their distribution is analogue to that found in the hands (4).

The AVAs drain almost exclusively to the superficial veins of the fingers, the dorsum of the hand, and the superficial venous rete of the forearm. At the level of the elbow, this rete drains centrally to the brachial venous system, whereas the nutritional vascular system drains to the deeper veins of the hands and forearm. As the AVAs when open, convey about 90% of the total blood supply to the hand, and the nutritive blood conveys only about 10%, it is reasonable to divide the vascular arrangements of the hands into a thermoregulatory and a nutritive component. The blood flow through the AVAs is responsible for the gross heat influx to the fingers and hand.

In cold man, where the AVAs are closed, and only the nutritive flow is supplying the tissues, this supply is not able to convey any heat to the hand. It has been shown (1), how the local hand temperatures of a cold man will fall at the same rate as that seen in a person at the same environmental conditions, but with a tourniquet around the upper arm.

If there is a counter-current heat exchange in cold man, it is based upon the blood flow through the nutritive vessels of the extremity.

In warm man, the superficial venous rete up along the forearm acts as a "heating glove", not only giving off heat to the environment, but also heating the underlying muscles, nerves, joints etc.



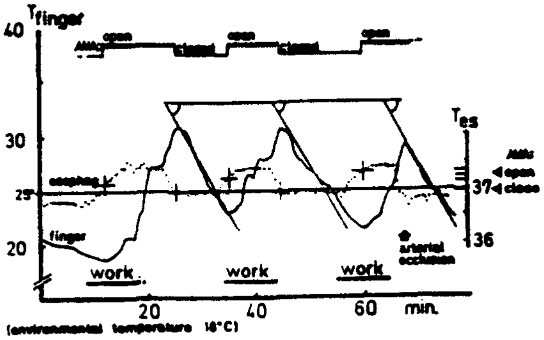
The vascular arrangement in the fingertip, where blood is distributed to the thermoregulatory vascular bed, draining to the dorsal superficial veins, and the nutritive vascular bed, draining to the deep veins(5).

REGULATION OF AVA FUNCTION

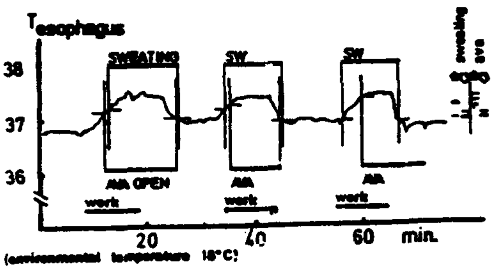
AVAs in hands and feet operate synchronously. In warm man they are open, although the blood flow may change from moment to moment, correlated to changes in the total sympathetic outflow. In the cold person the AVAs are closed, and remain closed until the central body temperature has risen to the normal level. If the concept of a "set-point" temperature is used, "set-point temperature" then

represents that thermal condition of the thermoregulatory centre where no regulatory reactions are elicited, the AVAs are open when central temperature is higher than the set-point, and the AVAs are closed when the central temperature drops below the set-point.

In contrast with the more generally accepted thermoregulatory models, this model involving AVA function is more simple, as it operates after an on-off principle, AVAs open or closed.



The unbroken curve shows the finger temperature of a man exposed naked to an 18 dg.C environment. The finger temperatures are given to the left. The broken curve shows the oesophageal temperature during the experiment. The experiment demonstrates how the finger temperature (dominated by the blood flow through the arteriovenous anastomoses) is related to the central body temperature (set-point temperature).



In the shown experiment, th[illegible] function is demonstrated. A naked person in a climatic chamber is exposed to an environmental temperature of 18 dg.C. Finger temperatures are measured to represent the AVA blood flow. Central temperature is measured in the oesophagus. As the person cools down, the AVAs close, the central temperature is lowered, the hand temperature falls steadily. As the finger temperature falls below 25 dg.C, the person begins a moderate work on a bicycle for 10 minutes. This work produces heat, and the central temperature rises. At a point, the finger temperature suddenly rises, but as the work stops, the central temperature levels off, and starts to fall. This fall in central body temperature is then followed by a sudden fall in finger temperature (the AVAs close), and the cycle is repeated. Parallel temperature changes are measured in the other extremities. At the end of the experiment, a tourniquet arresting the blood flow to the hand is established, to demonstrate that the fall in finger temperature in fact is caused by a very drastic reduction in blood flow (AVA closing). In the experiment, there seems to be a zone of around 2-3 tenths of a dg.C between central (= "set point temperature") closing and opening temperature. This could be compared to the "vasomotor thermoregulatory zone", but it could also just be a hysteresis due to the experimental set-up.

In the same experiment, sweating was measured, and the sweating pattern measured over the trunk and on the thigh followed the AVA function closely, was initiated at the same oesophageal temperature (set-point), and cessated, when the AVAs closed.

The experiment shows the central regulation of the AVA flow in the extremities. It demonstrates the all or none reaction of the AVAs. It demonstrates how AVA function and sweating are coupled, both reactions elicited at the same deep-body temperatures.

AVAs ROLE IN THE GENERAL THERMOREGULATION

In many textbooks, the physical vasomotor part of temperature regulation is often described as if the blood flow to the skin determined the heat loss from the body to the surroundings by increasing or decreasing the insulation of the skin. DuBois (6) demonstrated representative skin temperatures of nude resting man in still air at different temperatures. The curves showed that in a cold environment all skin temperatures fell. From weighting the different areas he proposed the concept of the average weighted skin temperature. But a closer study of his curves shows that this average skin temperature was most influenced by the temperatures in hands and feet. DuBois noticed this, and stated that in hands and feet, he chose the resulting temperature after 2 hours, as equilibrium never was reached. It seems fair to conclude that those skin areas whose temperatures are directly related to the AVA function play a specific role.

To this comes the common observation, that the surface temperature of the skin over the trunk of the body falls with increasing skin-fold thickness. The skin over the trunk seems to reflect the insulative properties of the underlying tissues, the subcutaneous layer of fat. Another common observation further indicates, that the skin of the areas not influenced by AVA function acts passively and without signs of any active thermoregulatory changes of insulation. When naked man is exposed to different cold environments, one would expect a kind of proportional increase in insulation, but this is not reflected in the skin temperatures, where a near linear relationship is seen between skin- and environmental temperature.

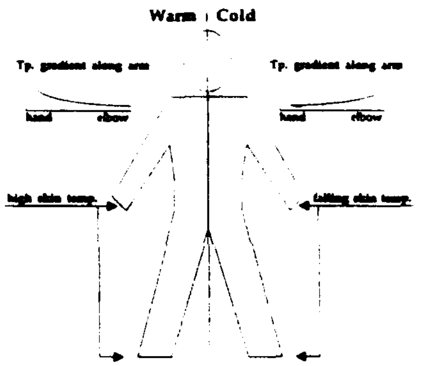
In the skin outside the AVA temperature dependant areas, blood-flow will vary with cooling of the skin. But here, there is the possibility of an effective counter-curent heat exchange between arterial and venous blood, where the temperature of the blood tends to follow the thermal gradiant of the tissue.

The AVA thus seem solely responsible for those thermoregulatory changes that are due to changes in skin blood-flow. Their role is further enhanced by the coupling between AVA

opening and onset of sweating.

The AVAs exert their effect not only in the relatively small skin areas covering the underlying anastomoses, but via the much larger skin area of the forearms and calves of the legs, where the subcutaneous veins drain the distally situated anastomoses. In a thermogram of the forearm of a warm person, the subcutaneous veins show up much warmer than the surrounding skin, demonstrating how they convey warm arterial blood. The blood in a warm person's veins is 100% oxygenated, demonstrating its arterial origin (7).

The author proposes, that the AVA system can be regarded as a specific thermoregulatory organ situated in the distal parts of the extremities, by its action ensuring the high and constant temperatures necessary for optimal physiological functioning in warm man. In cold man the AVA organ by shutting the peripheral blood down in the extremities defines the body shell, whereby the temperature of the body core is maintained as long as possible to enhance chances for survival - but at the expenditure of the extremities.



Skin temperature distribution in warm and cold man. In warm man, the distal parts of hands and feet are warm due to open AVAs. In cold man the temperatures of hands and feet are low, and continuously falling until they reach those of the environment.

PATHOPHYSIOLOGY OF LOCAL COLD INJURY

Local Cold injury, frostbite, occurs when tissue temperature falls below freezing point of the tissue. Around 90 % of all frostbites occur in the extremities and mainly in the feet (8). In warm man with his high hand and finger temperatures frostbite seldom occurs, and if it occurs, it is due to a very high wind-chill or to direct contact with cold surfaces or cold fluids. In cold man, where the temperatures of the extremities falls, frostbite will occur if the part cannot be kept warm by passive heating, i.e. by being placed in a local warm environment.

In cold and wet conditions, trenchfeet will occur if the feet have been cooled down to low, but not freezing temperatures for one or two days. In trenchfoot, the man is cold, his AVAS are closed, the local temperature falls. This fall in local temperature will affect the nutritive blood flow by increasing the viscosity of the blood (9), thus leading to hypoxia and subsequent necrosis.

In local cold injury, rewarming will often result in a high local blood flow, which lasts for at few days, and is then followed by decreasing blood flow, ending in gangrene. The high blood flow in the initial phases after thawing of the frozen tissue might be due to a high blood flow through the AVAs not accompanied by an increase in nutritive flow.

COLD-INDUCED-VASODILATION

Cold-Induced-Vasodilation or Lewis' hunting reaction is often described as a protective reaction, where the cold exposed extremity reacts to severe cooling (as when immersing the hand in ice water) by a local vasodilation. If cold exposure continues, the vasodialtion is followed by vasoconstriction, then subsequent vasodilation, showing a cyclic sequence.

But CIVD cannot be elicited in a cold person, only in a person with a high (above set-point) temperature. In a cold person, the exposed part will just cool more rapidly without any increase in local blood flow.

As the rapid temperature fluctuations seen in CIVD closely resemble those due to AVA function, the changes in CIVD might be due to AVA function. An open question is, whether the CIVD just reflects the normal thermoregulatory reactions, in this special situation provoked by the central inflow of blood cooled in the cold exposed part.

The fact that CIVD cannot be elicited in a centrally cold person points to such an explanation. Likewise that the periods in the cyclic pattern in CIVD can be changed by the degreee of cooling involved.

PATHOPHYSIOLOGY OF HYPOTHERMIA

Hypothermia is a lowering of the deep body temperature. In the hypothermic person, the extremities are cold, the AVAs closed. There is, at least in the initial phases, a clearly maintained body core and body shell. The arms and legs of the hypothermic victim are very cold. In the initial treatment, it is of importance that these thermal gradients are maintained. In the hypothermic victim the limbs are nearly bloodless. If circulation, especially in the AVAs, were opened up, this would mean that the warmer blood from the core would be cooled down, and on its return elicit an afterdrop in deep body temperature, which might be fatal.

As the AVAs together with the subcutaneous venous rete constitute a very effective heat exchanger (10), this might be used in the rewarming procedures. Rewarming in a hot water bath has always been the method of choice in rapid rewarming. If the person is to benefit fully from the hot water bath, arms and legs should be immersed, as this will facilitate the heat exchange between the bath water and the victim. Arms and legs thus should be immersed in the hot water in rapid rewarming procedures.

In the Danish Navy, where rewarming in a hot water bath is not always feasible, immersing the hands, forearms, feet, and calves in buckets filled and maintained with water at

42-44 dg.C is used. The efficiency of this method has lately been questioned(11), but in practice it has been shown to rewarm moderately cooled immersion victims rapidly.

In extreme heat situations, where the body is threatened by overheating and heat collapse, AVA cooling, where hands, forarms, feet and calves are immersed in cool water, shows that a considerable degree of cooling can be achieved. In this cooling, it is necessary to keep the water bath temperature above 15 dg.C, as intense vasoconstriction and eventually CIVD might be elicited if colder water is used. This would seriously impair heat exchange from the victim to the water.

PARADOXICAL UNCLOTHING

In people exposed to cold, a specific condition should be recognized. Hypothermic victims are often found naked or in a state of undressing. Often alcohol or other drugs may have been contributing factors in the development of the symptom(12).

People who have been rescued from hypothermia will normally will have amnesia, often retrograde, concerning their accident. But a few record that their last sensation was that of being extremely warm. One pilot ditching in ice cold water described his feeling as if standing before an open oven. He remembered that he felt it more urgent to try to cool himself in the ocean, than to enter the hoist.

The physiological explanation is unknown, but it could be conjectured that just prior to death, the cutaneous vasoconstriction cannot be maintained, and the last central blood suddenly heats the cold skin, giving rise to the sensation of extreme warmth.

IMPLICATIONS OF THE AVA CONCEPT ON THE DESIGN OF HAND- AND FOOTWEAR FOR THE EXTREME COLD.

The AVA concept of human thermoregulation gives the rationale for the fact that no mitten, glove or boot that will keep a cold man's hands and feet warm will ever be constructed. Good insulating materials may diminish the heat loss from a cold exposed person. But even with the best designed Arctic hand- and foortwear, frostbite may occur.

ARCTIC EXPERIENCES

It is the newcommer to the Arctic that is in danger.

Training and habituation to cold is of major importance. The training for working in cold need not be very long. Any person will, being given a thorough briefing, be ready to work effectively even in extreme cold.

In the Arctic, man's worst enemy is fear of cold. With the clothing issued by all the countries operating airplanes in the Arctic everybody will be able to carry out his duties.

Experience shows, that most problems in maintaining and operating airplanes in the extreme cold are not related to the personnel and its exposure to the cold, but to pure mechanical problems.

Man has lived and prospered in the Arctic for thousands of years. The limiting factor for Arctic operations is not physiological but mechanical breakdowns.

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Physiological Investigations of the Isolated Rat's Liver in Hypothermia and Hypoxia and their Relevance in Aircraft Incidents above the Sea.

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I. Introduction

Animals have two main methods of adjusting their body temperature. Poikilothermic animals basically adjust it to the existing ambient temperature whereas homoiothermic animals keep their core temperature at a relatively constant value which is frequently above the ambient temperature. These are thus able to stay physically active at all times, in contrast to poikilothermic animals whose metabolic processes slow down increasingly due to van't Hoff's rule when ambient temperatures are low, thus rendering the animal less active and sometimes even resulting in low-temperature rigidity. This, however, enables them to survive for a longer period of time in case of a lack of food and/or cold spells. Hibernating animals are something in between. In times of food shortage and in the period of cold weather, they reduce their metabolic processes and lower their body temperature. Without doubt, man is part of the group of homoiothermic organisms. However, when having a closer look at homoiothermic organisms, it becomes obvious that their body temperature is only constant as far as the body core and the vital organs are concerned - there are fluctuations in the temperature of the extremities, i.e. the outer parts of the body, which are mainly induced by the environment. Consequently, the tissue of these regions of the body is subject to changes in temperature which may be considerable without resulting in permanent damage. Findings mainly obtained from transplantation medicine have shown that the organs of the body core need not be damaged irreversibly either, if their temperature is lowered for several hours - on the contrary, they can even be preserved this way for a limited period.
If this means that man's vital organs as well as the skeleton and the locomotor system are relatively tolerant to cold if looked at individually, death by hypothermia may probably be considered a result of the dissociation of different functional systems and may even be accelerated by a maximum release of cate-

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cholamines. It thus seems to be caused by the failure of the regulation of vital systems which leads to a kind of shock. However, the release of catecholamines in itself may also result in death by immer-sion, as it is called, in the case of which ectopic brady-arrhythmia and myocardial ischemia accompanied by a massive increase in blood pressure are of primary importance. Air crew members after bail out above the sea as well as victims of naval accidents face this danger. As accidents of this kind cannot be prevented in all circumstances suitable protection and appropriate emergency therapy have to be provided to reduce the effects of cold on man.

In the course of investigations which were carried out using a rat's liver perfused by a haemoglobin-free solution as a model, findings were obtained which may lead to a reconsideration of current treatment schemes of hypothermia.

In this context, the liver is of special interest because on the one hand, it is an organ which is particularly affected by the redistribution of the cardiac output to the advantage of other organs which is caused by the shock. On the other hand, it also may well play a central role during the shock itself, for example due to its clearance function in the first-pass-effect, i.e. by neutralizing substances which have crossed the intestine-blood-barrier which collapses as a result of the damage done to the organism as a whole. DAHN and LANGE have shown that the percentage of the body's total oxygen consumption taken up by the splanchnic organs amounts to 20 % in the case of a trauma and increases to even 44 % in the case of sepsis. Furthermore, the liver's capacity to form new glucose from lactate and alanine - which is dependent on energy - is of decisive importance particularly in states of shock with accompanying acidosis caused by lactic acid, because the muscular system and above all the brain depend on glucose as an energy-providing substrate.

II. Method:

After rats had been given 6 mg of Pentobarbital/100 g - that is a lethal dose - their livers were taken out after cannulation of the portal vein and the proximal lower vena cava and integrated into an artificial circulatory system (fig. 1).

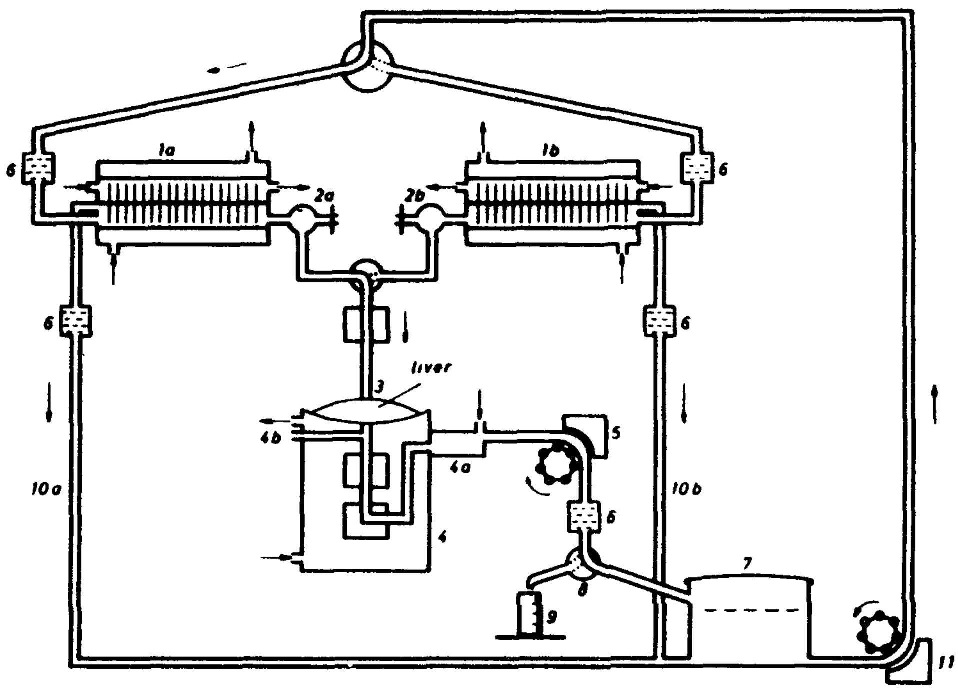

Fig.1: Scheme of the perfusion set-up. 1a,b oxygenators; 2a,b bubble traps; 3 cannula into the portal vein; 4 vessel for venous analysis, 4a storage vessel; 5 roller pump; 6 defoamer; 7 collector; 8 three-way cock; 9 measuring cylinder; 10a,b overflow connections; 11 roller pump

An albumin-salt-solution was used for perfusion according to KREBS-RINGER-HENSELEIT and was saturated in disk oxygenators with gas mixtures. These gases contained 5 % carbon dioxide each, the rest was either nitrogen or oxygen. The hydrostatically produced perfusion pressure amounted to a water column of 15 to 17 cm. The flow was continuously measured using an electromagnetic flow meter. It remained at a relatively constant 3 ml/g of liver/min or more for the entire duration of the experiment. When combining these values with the values measured by oxygen electrodes at the points of influx and outflow, it was possible to continuously determine the oxygen consumption of the liver, too. Finally, the local partial pressure of oxygen on the surface of the liver was

determined polarographically using a multichannel electrode (MDO) according to KESSLER and LÜBBERS (fig. 2). At the end of the experiment, some livers were fixed by means of formalin perfusion and prepared histologically.

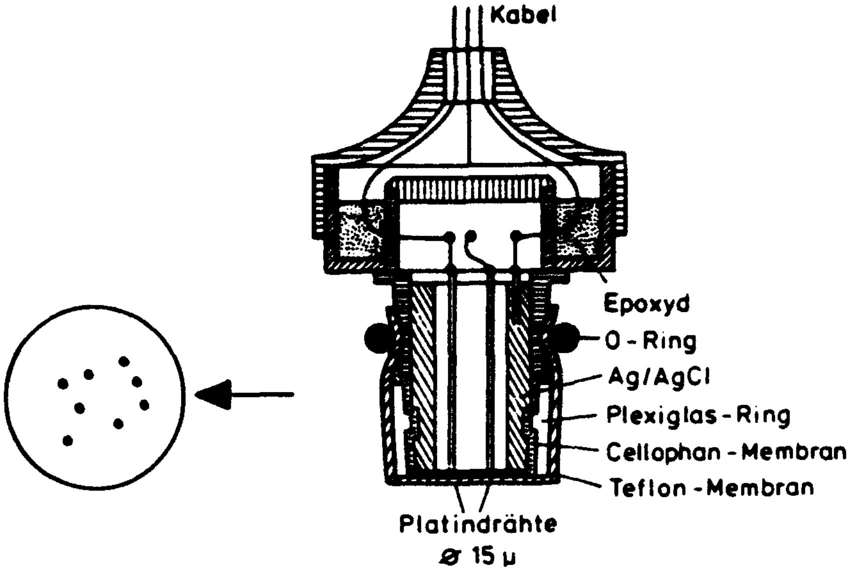

Fig.2: Cross section and pO_2 measuring surface of the multi-channel-electrode (MDO) (Platindrähte = platinum wires, Kabel = connecting line, Plexiglas-Ring = acrylic glass ring)

III. Results:

In the case of all experiments, the livers which had been taken out quickly cooled down to the room temperature in the laboratory. This was between 22 and 27°C (approx. 72 and 81°F) and was constant for every individual experiment. After the flow rate had stabilized after the removal of the livers, phases of hypoxia were produced by switching the gas mixtures which lasted six minutes (fig. 3).

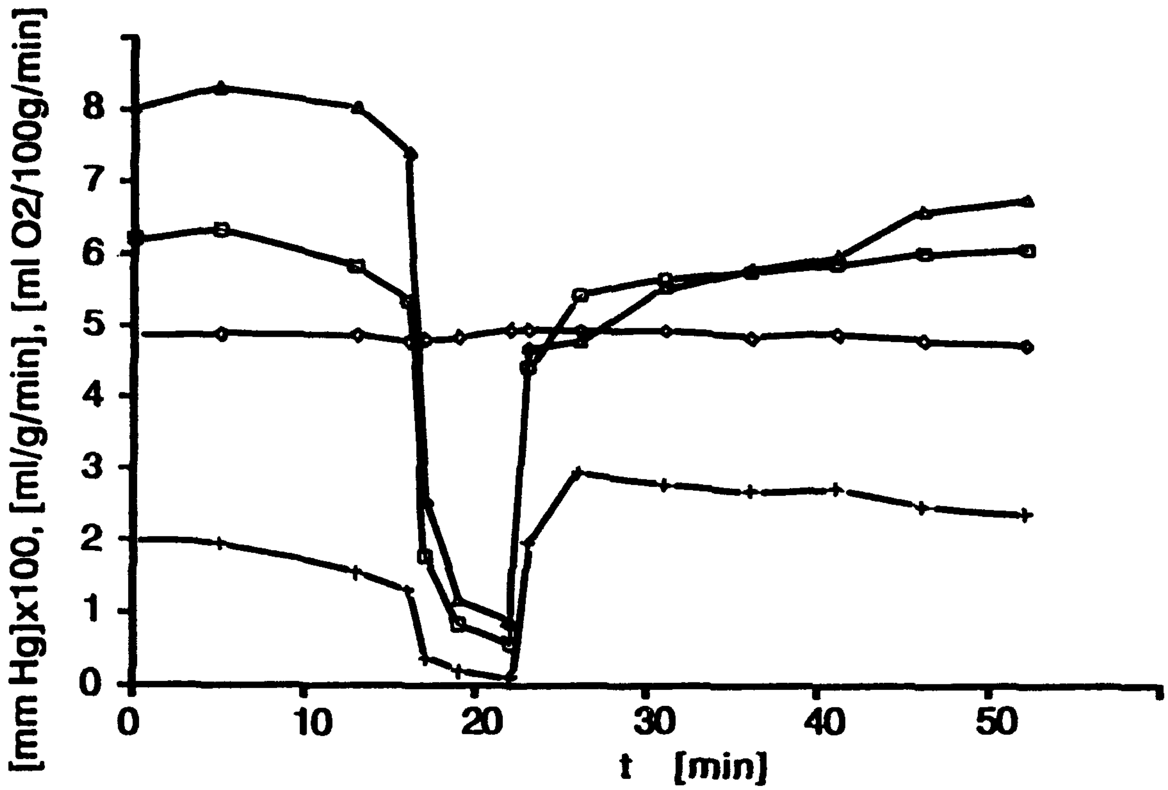

Fig. 3: Oxygen consumption (▲), flow rate (◇) and pO_2 at the points of influx and outflow (□,+) before, during and after 6 minutes of anoxia

In some case noradrenaline had been administered before. During the experiment, the partial oxygen pressure decreased very quickly at the points of influx and outflow, and the values measured on the surface of the liver were mainly anoxic ones. After switching back to aeration with 95 % oxygen, oxygen consumption increased after a delay and reached its original level only after 20 to 30 minutes although the pre-hypoxic partial oxygen pressures had been reached at the point of influx after only 5 minutes. 5 minutes after the end of hypoxia, consumption had been lowered by more than 20 % on average. This reduction could be avoided completely by administering noradrenaline before hypoxia. Monitoring the local partial

oxygen pressures on the surface of the liver shows, on average, a quicker increase in the case of experiments without the use of noradrenaline which is basically a result of the quicker increase in the extremely low values (fig. 4).

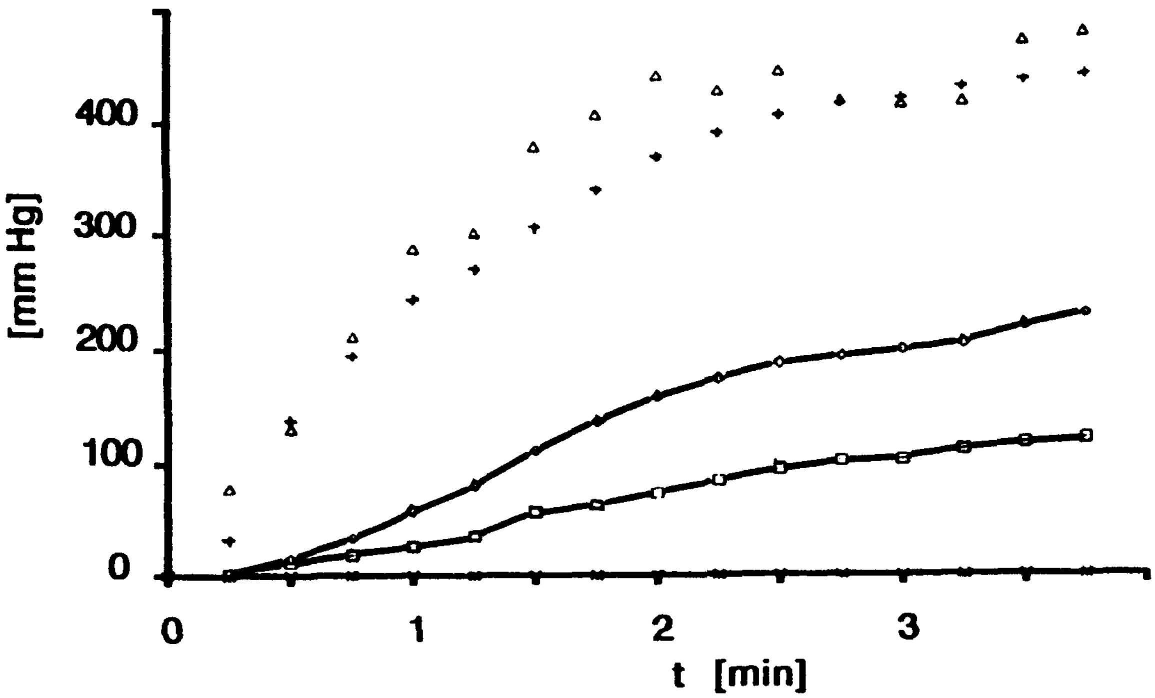

Fig.4: Maximum, average and minimum values of the local partial oxygen pressures after hypoxia in experiments without (△, ◇, ▽) and with (+, □, ×) administering noradrenaline before. n = 49; the value "0" occurs considerably less frequently after 3.5 minutes in the case of the experiments without noradrenaline

On completion of the experiments, which had lasted several hours, intracellular vacuoles could only be found in a few of the organs checked. Necroses or other irreversible changes could not be detected (fig. 5).

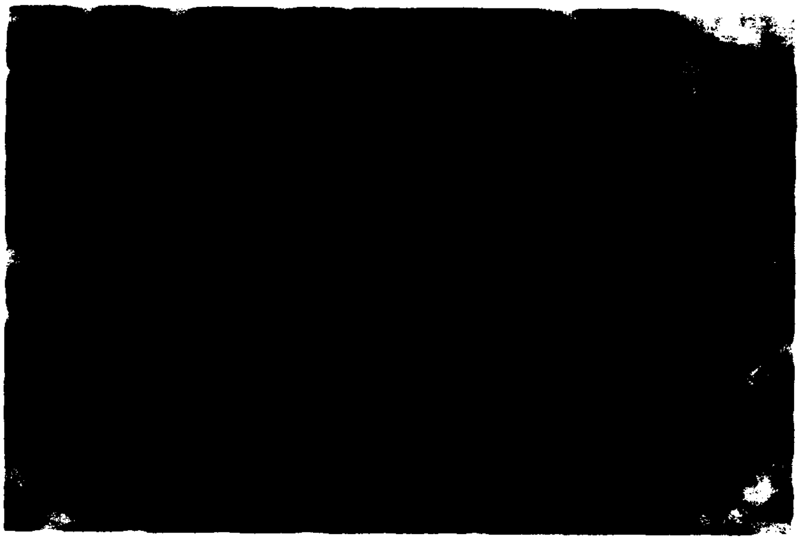

Fig.5: Photo of a detail of the liver with peritoneal lining (P) (fixing by means of perfusion using formalin; hematoxylin eosin staining, 160x)

IV. Discussion

Isolated livers of rats perfused by a haemoglobin-free solution, which were introduced by MILLER et al. in 1951, have proved their worth as models for the following reasons:

- hormonal and nervous influences are excluded and
- due to the lack of haemoglobinous corpuscular oxygen carriers there is a linear connection between pO_2 in the perfusion solution and the oxygen content.

However, the lack of oxygen carriers necessitates a high partial pressure in order to dissolve enough oxygen physically. At the same time, the metabolism of the liver must be reduced by hypothermia. Under these conditions, however, the organ can be preserved for hours without an oedema which would point to a collapse of energy-dependent ion gradients or a morphologically identifiable irreversible damage. On the contrary, recurring reactions to hypoxic states could be identified during hypothermia: In the case of the present experiments, the temporary reduction in oxygen consumption which occurred after hypoxia when the oxygen supply had already reached its maximum again may be interpreted as an inhibition continuing after the end of hypoxia. The course of the curve suggests that during hypoxia, a mediator causing this inhibition appears in the organ itself which first has to be eliminated after hypoxia. A benefit of this inhibition seems to be the redistribution of the existing residual oxygen for optimum utilization during the phase of hypoxia. This is proved by the quicker increase in particular of the very low local pO_2 values towards the end of hypoxia in comparison with those experiments where an inhibition was prevented by administering noradrenaline before. Noradrenaline not only has a general perfusion-reducing effect, e.g. in the liver, but also seens to influence the protective mechanisms of the liver against oxygen deficiency.

For physical reasons, the perfusion solution had to be aerated using 95 % oxygen in the present experiments in order to obtain a sufficient quantity of oxygen in solution. It is known from a paper by MILLER and KESSLER that in the case of rats supplied with oxygen in normothermia, the gradual replacement of oxygen by carbon dioxide up to a percentage of 40 % CO_2 leads to a significant increase in the partial oxygen pressures in the liver. Immersion of the animals in ice water results in the temperature of the liver going down to 17°C (approx.63°F) and leads to anoxia of the liver due to vasoconstriction if air is breathed. If, however, the animals are caused to breathe 5 % oxygen, 30 % CO_2 and 65 % nitrogen, the oxygenation values of the liver will finally equal the normothermal initial values whereas a mixture consisting of 10 % O_2, 25 % CO_2 and 65 % N_2 results in almost no improvement compared to the breathing of air in hypothermia.

Ventilatory Gas mixture (missing: N_2)	Air	40% CO_2 60% O_2	30% CO_2 5% O_2	25% CO_2 10% O_2
Temperature	Normo-thermia	Normo-thermia	Hypo-thermia	Hypo-thermia
pO_2 Liver (mean value) [mm Hg]	20	150	25	5

from: Miller JA, Kessler M

When dealing with hypothermia, it thus seems to be necessary to particularly consider the constriction effect of pO_2 and the dilating effect at the vascular bed which directly depends on pO_2. However, in this context the question arises what consequences this has with respect to the acid-base balance and metabolic changes. Existing data do not provide a clear answer to this question. If following the argumentation of RAHN, an extreme respiratory acidosis would probably be considered to be present: It could be shown that poikilothermic animals increase their pH value with decreasing temperatures. This change in the pH value occurs almost parallely to the temperature-dependent change of the neutral point of water. This would mean that the physiological pH value would be approximately 7.7 at a temperature of 15°C (about 59°F). Of course, an acidosis leads to an inhibition of metabolism (just like hypothermia) and thus of the liver's central function for the body's metabolic process, which, however, the body seems to be able to tolerate for some time. But the organ's increased perfusion rate under the last-mentioned conditions contributes to the preservation of the liver's structure: HÖPER (1986) showed that oxygen deficiency alone is tolerated without any problems whereas impairments of perfusion quickly lead to irreversible damage to the organ.

What are the conclusions?

From the point of view of experimental physiology, it thus seems to be advantageous to give an animal which has been exposed

to hypothermia and which is not hypovolemic artificial respiration using a mixture with a high CO_2 and a relatively low O_2 content: Good perfusion of the liver contributes to the preservation of the organ. The accompanying reduction in metabolism (detoxication, gluconeogenesis) will probably not fully take effect at first: For example, glucose may be mobilized from the places where glycogen is stored without any energy consumption, and toxic substances contained in the intestine are more likely to penetrate rather gradually than immediately and massively. After warming up and stabilization of the circulatory function, the liver, which will still be functional, may contribute to the compensation of secondary effects of hypothermia such as hypoglycemia and toxicemia in the case of "shock intestine" with its full metabolic capacity.

The authors of this lecture work in the field of theoretical medicine and do not want to post advices for the treatment. Rather the experimental results are bound to stimulate the reconsideration of present treatment schemes of hypothermia.

V. Summary

As accidents with bail out of the air crew cannot be prevented in all circumstances considerations must point towards suitable protection and appropriate emergency therapy for what only experimental investigations are suited.
Hypothermia can be tolerated by an isolated rat's liver for hours without leading to irreversible damage. In addition, it does not block the organ's inherent protective mechanisms.
Noradrenaline deteriorates the local oxygen supply of the liver in hypothermia whereas the use of low oxygen and high carbon dioxide concentrations during respiration seems to make it possible to overcome vasoconstriction caused by cold.
In experimental hypothermia in animals, such a temporary respiration seems to be advantageous because this may, among other things, make it possible to preserve the liver's structure which thus will make its full metabolic capacity available after normothermia has been reached again.
Our experimental results gained from animals seem to be important in respect of clinical treatment schemes of hypothermia.

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AEROPATHOLOGICAL DIAGNOSIS OF LETHAL HYPOTHERMIA

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SUMMARY

The decrease of central body temperature by warmth withdrawal leads in most cases to pathological changes of signal devices as the energy metabolism. The central body temperature may be lowered to 28 - 26°C without irreversible disturbances of life functions occuring. Not earlier as below 26°C rectal temperature life sustaining becomes critically. With continued exposure to cold and missing therapy hypothermia passes several phases. Below 26°C rectal temperature in a phase of paralysis death occurs with cardiac disturbances like cardiac oscillation and disorders of atrio-ventricular conduction. Findings on the corpses of persons dying by cold exposure are discussed. Findings of a crew member dying after ejection and immersion in cold water are demonstrated and weighted by means of differential diagnosis.

INTRODUCTION:

Three categories of causes of death are mainly considered in the case of fatal bailout over the sea:

1. Blunt force and whiplash injury
2. Drowning and its atypical forms or "death in the water"
3. General hypothermia.

Whereas the effects of blunt force can be determined clearly and without significant complications even macroscopically, differentiating between the two other causes of death, i.e. drowning and hypothermia, involves certain difficulties, especially because sometimes "mixed forms" may be present due to incomplete or atypcial processes during drowning, including even reflex death or sudden death in the water - each of them occurring together with general hypothermia.
Finding out about the actual cause of death is of considerable importance on the one hand for the reconstruction of the circumstances of the accident and its individual phases and on the other hand for possible conclusions with regard to prophylactic measures aimed at the prevention of accidents or with respect to modifications in the equipment and clothes or the regulations. We would like to demonstrate the difficulties encountered when trying to determine the cause of death with the help of one case.
First some theoretical explanations as far as the differentiation between the two categories of causes of death is concerned.

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

WHAT IS THE DIFFERENCE BETWEEN DROWNING AND SUDDEN DEATH IN THE WATER, AS IT IS CALLED, WITH RESPECT TO THE PATHOPHYSIOLOGICAL PROCESSES INVOLVED, AND WHAT FINDINGS ARE GENERALLY TO BE EXPECTED IN THE CORPSE?

1. Drowning refers to the occlusion and partial filling of the respiratory tract with liquid. In this context, it is completely sufficient if the nose and the mouth are immersed in the liquid. Death by drowning is to be considered violent external suffocation. It may either be typical drowning, as it is called, in the case of which there are several changes from aspiration of water to aspiration of air and vice versa or atypical drowning, which means that water is breathed permanently.
2. A differentiation must be made between sudden death in the water, as it is called, and death by actual drowning.
   The cause of death is not drowning in the case of sudden death in the water; however, there is no clear distinction between sudden death and drowning. It may be mere coincidence that the person concerned is in the water, e.g. in the case of cardiac infarction or coronary occlusion, the rupture of an aortic aneurysm, etc.; but it may also be the reason for organic and functional processes which lead to death before actual drowning would have occurred. Let me mention some examples: Acute cardiac failure in case of weak cardiac output due to stress caused by cold, fear or panic, fatal reflex laryngeal shock due to the irritant effect of water swallowed, cardiovascular failure or a state of collapse in the case of a very full gastro-intestinal tract accompanied by digestive hyperemia, etc. Other causes may be, for example, spasms and fits or also vertigo or fainting fits. This explains why it is often difficult to draw the line between these forms which can not be classified clearly. Pathological disturbances or debility may modify the process of drowning; they may trigger it such that all its stages take place or they may cause it to take place in a quantitatively weaker form. Theoretically, the component of drowning or suffocating actually can only contribute insignificantly to the occurrence of death.
   The complete process of drowning takes place in six pathophysiological stages and, as a rule, will last between three and five minutes. Part of the liquid swallowed is resorbed into the circulation from the overstretched and torn alveoli but partly also from the mucous membranes of the bronchial system. This applies to hypotonic solutions, such as freshwater. Except for the Baltic sea, in which case there are approximately physiological sodium chloride concentrations, drowning in salt water is a matter of hypertonic solutions. In this case, only a small portion of the water absorbed is resorbed into the blood stream. Only the salts diffuse into the blood whereas proteins of the blood plasma pass into the alveoli due to the osmotic and colloid osmotic difference in pressure in both directions.
   The pulmonary changes, which

are a result of the mechanical influence during the process of drowning, depend on the intensity and duration of the individual stages of drowning. They are more pronounced in the case of typical drowning than in the case of atypical drowning and are not present at all in the case of sudden death in the water, as it is called. The external findings are not characteristic as far as the diagnosis of the corpse is concerned. Even the formation of foam at the mouth and at the nose does not mean much because it also is found in the case of other causes of death, e.g. in the case of a pulmonary edema or an epileptic fit. However, in the case of typical drowning, as it is called, the post-mortem findings in the lung are quite typical:

- The lung is severly distended and blown up like a balloon. On opening the pleural cavity, it is found that it not only fills it completely but sometimes even protrudes from the breastbone.
- Frequently, indistinct salmon-red hemorrhages covered with small spots are found in the pulmonary pleura, i.e. Paltauf's hemorrhages, which mostly extend to the boundaries of the lobules and which have developed from ruptured vessels in distended tissue with subsequent hemolysis after contact with the liquid swallowed during drowning.
- Another characteristic is the fact that the volume of the stiff tissue clearly stays constant, which means that pits remain when pressing one's finger into it. On the cut surface, the tissue is pale and dry, looking patchy and marbled. In the bronchial system, liquid swallowed during drowning and mucus is found, often mixed with air, forming foam with small bubbles.
- Microscopically, a severe emphysema with greatly dilated alveoli whose septa are lacerated at various points can be detected. Sometimes, foreign matter from the liquid swallowed are found in the bronchial system.
- In contrast to this, the characteristic pulmonary emphysema is not present in the case of atypcial drowning. The lungs are heavier and are found to have absorbed an increased amount of liquid during drowning. Furthermore, the tissue contains more blood.
- The diagnosis of death by drowning is based primary on the macroscopic and microscopic post-mortem findings; however, the detection of diatoms, which are generally contained in stagnant and running bodies of water, in the lungs and in particular in the organs of the greater blood circulation can be considered a proof if considerable quantities of these diatoms are found in the greater blood circulation. A comparison of the diatoms in the greater blood circulation with those isolated from a sample of the medium in which drowning occurred is a prerequisite for this proof. It is more difficult to name the cause of death if the traditional signs of drowning are lacking and atypical processes, as they are called, mixed forms or even other causes of death

happened to lead to death in the water. In this context, cases of reflex death must be mentioned in particular which result in cardiac standstill via the vagus nerve before actual drowning has occurred.

As far as bailout from aircraft over the sea is concerned, local cold injuries are not as important as general fatal hypothermia. In this context, it must be mentioned that people in danger of dying from exposure often behave in a paradoxical way, for example taking their clothes off. This is referred to as delirious states in people dying from exposure, i.e. "cold idiocy", as it is called.

PATHOPHYSIOLOGICAL PROCESSES IN THE CASE OF GENERAL HYPOTHERMIA

Due to the dependence of the dissociation curve of Hb on the temperature, general chilling leads to hypoxidosis and then, as a further consequence, to a general reduction in metabolism, to the compensatory redistribution of the blood from the periphery to the core of the body and to the shift of water from the blood to the tissue. The decrease in usable oxygen and the requirement lead to a decrease in the excitability of the cerebral centers and finally to their complete failure. In addition, it must be considered that a reduction in metabolism and a drop in the body temperature below the optimum reaction temperature of the vital fermentation systems lead to an interruption of all vital processes and thus to the slow occurrence of death. On the other hand, general hypothermia may lead to lethal ventricular fibrillation due to the shortening of the refractory period of the cardiac musculature and the prolongation of conduction.

As a rule, 20 - 25 °C (68 - 77 °F) are considered critical values of minimum body temperature. In the case of general hypothermia, local damage to cells or tissue is generally not to be expected because death ensues already before due to the fact that central functions are put out of action.

WHICH FINDINGS ARE TO BE OBTAINED IN THE CORPSE IN THE CASE OF SLOW CHILLING?

Due to the more stable bond of oxygen to hemoglobin, light-red post mortem lividity must be expected. Due to hyperemia of the internal organs, punctiform hemorrhages covered with small spots and even erosions are present in the area of the mucous coat of the stomach; in addition, there are hemorrhages of the pancreas as well as subepicardial, intrapulmonary and subpleural hemorrhages.

In the case of general hypothermia, microscopic findings are either extremely insignificant or not characteristic or mainly characterized by findings of shock and may well be compared with the findings in case of external heat injury.
In addition to hemorrhagic pancreatitis, micro-infarcts are found in almost all organs. They are caused by agglutinates of erythrocytes in the small vessels, by a reduction in glycogen in the heart, liver and kidney and by the deposition of protein in the capsule of the malpighian glomerulus as well as by a severe reduction in lipoids in the suprarenal body.

On the whole, it may be emphasized that, if looked at individually, the findings in internal organs obtained in the case of general hypothermia may also be the result of other causes not related to

hypothermia and thus are not specific enough for the diagnosis "death by general hypothermia". If the actual cause of death is to be determined, it is therefore absolutely necessary to also consider the overall circumstances. In the case of death by cold, both the macroscopic and the histomorphological findings essentially correspond to the findings after states of shock. They are not sufficient to justify the diagnosis of "death by cold" from a forensic point of view.

In this context, it is thus required to exclude other possible pathological causes of death or their contribution and, in any case, to include all the exact cicumstances of the occurrence of death into one's considerations. In the assessment of the aircraft accident already presented in lecture no. 16 which involved ejection of all of the four crew members over the sea, one of whom did not survive, the following findings had been obtained as a result of the post-mortem examination:

- light-red post-mortem lividity
- general plethora of the internal organs
- dilatation of the brain with signs of cerebral pressure
- plethora and patchy blood distribution in the area of the heart
- patchy blood distribution in the area of the lung with Paltauf's hemorrhages and severe pulmonary edema
- foam with small bubbles in the respiratory tract
- patches of hemorrhages of the mucous coat of the stomach
- focal hemorrhages of the pancreas.

Under the microscope, small hemorrhages were found in the brain, lung, pancreas, kidney and suprarenal body. In addition, there was a large quantity of macrophages in the lung. The examination of the lung and organs of the greater circulation such as the liver and kidney - which had been subjected to wet incineration for the search for diatoms - showed that in the organs of the greater blood circulation, no diatoms were present.

The overall macroscopic and microscopic findings including the high-grade plethora in central areas point to a shock; the hemorrhages of the mucous coat of the stomach as well as the hemorrhages of the pancreas, which microscopically exhibited the findings of hemorrhagic pancreatitis, suggest a process of hypothermia as the most likely cause.

The light-red post-mortem lividity, the foam with small bubbles in the respiratory tract, the Paltauf's hemorrhages of the lung suggest an atypical process of drowning. However, in this context, the pulmonary edema and the fact that there was no emphysema of the lung do not indicate a traditional and complete process of drowning, especially since no diatoms could be found in the organs of the greater circulation. This means that an atypcial process of drowning is considered a factor which contributed to the occurrence of death.

A systematic check of the internal organs had shown that there was no evidence whatsoever of pathological changes which could possibly have contributed to the occurrence of death or be a relevant factor.

Due to the fact that both the macroscopic and microscopic findings are relatively nonspecific on the whole, the overall circumstances must also be taken into consideration in a case like this.

Provided the statement by one of the crew members who said that the weapon system operator who died later had been able to talk to him after he had called him and had confirmed that everything was OK is true, it must be taken as a basis that the death was not caused by ejection from the aircraft since there was no fatal blunt force. Furthermore, it must be assumed that at first, the weapon system operator's state of consciousness enabled him to also act purposefully. Consequently, there is no evidence of reflex death caused by contact with cold air or cold water. Since everything else can be excluded, drowning and hypothermia are considered the most likely causes of death. Since it is hardly possible that a human corpse lying in the water without active heat transport, i.e. blood circulation, cools down from a body temperature of approximately 37 °C (about 99 °F) to a body temperature of roughly 28 °C (about 82 °F) if the water temperature is 11 °C (about 52 °F) - which was measured during the rescue operation - within 2 hours and 15 minutes, it must be assumed that the crew member had survived for a relatively long period. Accordingly, the drop in the body temperature probably was a vital process, as it is called. This could also easily be brought in line with the signs of hypothermia found during the post-mortem examination, i.e. the hemorrhages of the mucous coat of the stomach and the hemorrhages of the pancreas. We know from pathophysiology that in case of temperatures below 30 °C (86 °F) unconsciousness and thus inability to act are to be expected. During this period, i.e. when the weapon system operator was unable to act and was lying in the special position the corpse was later found in in the water, i.e. with the head and the breathing orifices such that sea water could flow in and out, atypical drowning may have set in which finally put an end to the process of dying. This is also an explanation for the incomplete signs of drowning in the corpse.

To sum up, one can say that in the case of fatal accidents over the sea, the diagnosis of causes of death may be difficult due to the fact that the findings in the corpse do not provide clear proofs. For the final determination of the cause of death, the overall circumstances with respect to the position of the person concerned as well as time factors and pathological factors must in any case also be taken into consideration.

The literature will be available at the author's adress.

REWARMING METHODOLOGIES IN THE FIELD

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INTRODUCTION

Hypothermia may occur with prolonged exposure to cold air or water (1,2,3). Recovery from hypothermia involves removing the individual from the cold environment and utilizing a rewarming strategy. Three major rewarming strategies include: 1) passive rewarming, 2) active external heating, and 3) active internal heating. Controversy continues regarding the best rewarming procedure for use in the field.

During passive rewarming, the individual is removed from cold air or water, dried off, placed in a sleeping bag, and allowed to shiver until fully recovered. Provided that the cold stress has been sufficiently removed, it is assumed that the body can spontaneously generate sufficient heat to rewarm itself (2).

Rapid external rewarming is the application of direct heat to the external body surfaces. Rewarming is thus facilitated by heat generated from external sources. Examples of rapid external rewarming include: warm water baths, heat cradles, diathermy, and liquid heated suits (2,3).

Active internal rewarming involves administering heat directly to the "core" of the body, which is usually considered the contents of the trunk beneath the skeletomuscular and adipose shell (2). Examples include: peritoneal dialysis, mediastinal irrigation, extracorporeal circulation, hemodialysis, and intragastric or colonic lavage (2,3). These methods involve surgical procedures and are not practical in a field setting. However, an active internal technique for the field is the breathing of warm, humidified air. Warm moist air is also used in hospitals to help rewarm surgical patients (4,5,6,7,8). The problem is that most of the devices are bulky, heavy, and impractical to use in the field. While investigating a field device used to provide warm humidified air, Sterba (9) had a problem with excessive inspiration temperature.

One study (9) concluded that only passive heating should be done in the field, while others (8,10,11,12,13,14,15) contend that active external, or active internal (5,6,7,8,16,17,18) strategies should be employed. One problem with active external or internal rewarming is that shivering may be decreased, resulting in slower rewarming (13,19). The purpose of this study was to compare the effectiveness of three field rewarming procedures: 1) United States Marine Corps (USMC) issue extreme cold-weather sleeping bag, 2) cold-weather sleeping bag with external heat applied using a Heatpac device, and 3) cold-weather sleeping bag while breathing warm, humid air from a Heatpac with Humipac (prototype) attachment.

METHODS

Six male subjects participated in this study. The physical characteristics of the subjects are presented in Table 1.

Medical Screening

Subjects were informed of the nature, purpose, and potential risks of the experimental procedures, and they signed informed consent and privacy act statements. All subjects underwent medical screening, which included a medical history questionnaire, body composition assessment, and clearance to participate by a medical officer. Height and weight were determined by standard methods. Body density was determined using skinfolds from three sites: chest, abdomen, and mid-thigh (20). Body fat was determined from body density using the Siri equation (21).

Measurement Systems

A Polar Vantage XL monitor (Polar USA, Inc., Stamford, CT 06902) was used to determine heart rate. Core temperatures were measured using sterile disposable Sher-I-Temp thermistors. Skin temperatures were measured using silver skin thermocouples. A Grant 1200 series (12-Bit) Squirrel Meter/Logger was used to record core and skin temperatures.

Oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were determined using open-circuit spirometry. Expired gas was collected for 1.5 minutes in a Collins 100 liter plastic bag connected to a Hans-Rudolph two-way valve. Expired air was analyzed for O_2 and CO_2 using Amatek S-3A/I oxygen and CD-3A carbon dioxide analyzers (Amatek, Pittsburgh, PA), respectively. Expired gas volume was measured using a gas meter (Rayfield Equipment, Waitsfield, VT). Blood pressure was measured using a digital blood pressure monitor (Carolina Biological Supply Co.).

Experimental Protocol

Each subject reported to the laboratory on three separate days within a one-week period. The influence of circadian rhythms on body temperature was controlled by conducting each test at the same time of day (22). Rewarming methods were

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presented to each subject in random order. The three methods included passive heating (shivering in the sleeping bag), active external heating (shivering in the sleeping bag with external heat provided by a Heatpac), and active internal heating (shivering in the sleeping bag with Heatpac plus Humipac attachment). The testing protocol consisted of 15 minutes of rest in air at room temperature (23°C), cold water immersion (12.1°C) for up to 85 minutes, four to eight minutes of transition to the rewarming bag, and rewarming for 120 minutes. Measurements included rectal (T_{re}), esophageal (T_{es}), and mean weighted skin temperatures (T_{msk}) (23), as well as heart rate (HR) and oxygen uptake ($\dot{V}O_2$).

Subjects fasted for 10 hours prior to each test. Upon arrival to the laboratory, body weight was recorded. Each subject then inserted a rectal thermistor to a depth of 20 cm. An esophageal probe was inserted to heart level. Skin thermistors were placed on the forehead, right cheek, right biceps, right chest, right front mid-thigh, and right back mid-calf. A heart rate telemetry monitor system was placed around the torso at chest level. During the test, each subject wore a bathing suit/shorts.

Baseline measurements of blood pressure, T_{re}, T_{es}, skin temperatures, HR, and $\dot{V}O_2$ were recorded after 15 minutes of rest at room temperature (23°C) immediately before cold-water immersion. Each subject then lowered himself into the cold water bath (12.1°C ± 1.3) and sat on a chair with the water level up to the apex of the sternum. Recorded cooling time began once the subject was seated. The subject remained in cold water until either his rectal temperature dropped 1°C from baseline, he requested to get out, or after a total elapsed time of 85 minutes. During immersion, HR, T_{re}, T_{es} and skin temperatures were recorded every five minutes. At the end of immersion (before exiting the cold-water bath), $\dot{V}O_2$ was determined, and body temperatures were recorded again.

After completion of the cold-water immersion, the subject climbed out of the water tank, dried off, changed into dry shorts, and climbed into the sleeping bag placed on a gurney. Transition time into the bag ranged from four to eight minutes. Skin temperatures, T_{re}, and T_{es} were recorded at five minute intervals throughout rewarming. $\dot{V}O_2$ was determined at 15, 45, 90, and 120 minutes of rewarming.

Rewarming Systems

The rewarming systems included· 1) the sleeping bag (SB), 2) sleeping bag with Heatpac (HP) (Alcatel Innova, Norway), and 3) sleeping bag with Heatpac plus Humipac attachment (HHA) (prototype Alcatel Innova, Norway). The sleeping bag was a USMC extreme cold weather bag II, weighing 4.3 kg and rated for temperatures to -50°F. Insulation consisted of waterfowl feathers, down, and polyester batting.

The Heatpac (HP) is a portable heater weighing 750 g. It utilizes heat from a slow-burning stick of charcoal, assisted by a battery- (size "D" dry cell, 1.5 V) driven fan. The fan pulls air into the unit and pushes it out via heat tubes or tentacles. A catalytic converter removes carbon monoxide and other gases from the burning charcoal. When in use, four heat tubes or tentacles are attached to the HP. The HP is placed inside the sleeping bag near the feet, with the exhaust vented outside of the bag. Inside the bag, two tentacles are placed along the sides of the body, while the other two tentacles are placed on the inside of each thigh.

The Heatpac with Humipac attachment (HHA) is a prototype device that weighs 2.0 kg. Air flows from the HP through the Humipac attachment to a face mask from which the subject inhales and exhales. The Humipac attachment is a double-tube cylinder (one tube inside the other). The inner chamber is lined with a moisture-absorbent material. A 100 ml plastic reservoir is connected to the inner chamber. The reservoir is filled with water, then "squeezed," pushing water into an inner chamber. The moisture-absorbent material then becomes saturated; absorption capacity is 200 g. During operation, warm air flows through the chamber and becomes saturated with water.

During rewarming with the HHA, a temperature probe was placed directly above the area where the warm, humidified air first exits the HHA. The mean near-inspired air temperature exiting the HHA was 50.9 ± 3.6°C (Fig. 1). The air then travels through a 10 cm rubber neck, through a two-way valve, and into the face mask. Preliminary studies on the HHA (unpublished data) reflect actual inspired air temperatures 2 to 6°C less than temperature coming directly out of Humipac. For this study, the range of air temperature entering the mouth ranged from 45.4 to 47.9°C.

In this study, the charcoal fuel element was ignited at the start of immersion, allowing the HP and HHA to warm up for at least 40 minutes. In all tests, the HP or HHA was set on its highest temperature setting. The HP produced air temperatures of 64.9 ± 0.8°C (Fig. 1).

During rewarming, the HHA is placed on the subject's chest. The subject's nose and mouth are covered by a standard oral-nasal mask, and the subject inhales warm, humid air. Exhalation is vented to the atmosphere by a two-way valve attached to the mask. The main body of the HHA generates heat to the chest area. The HHA has a cloth cover over the HP and Humipac. During each test the relative humidity of the air going to the subject from the HHA was checked before and after application, and was constant at 100 percent. All experiments were conducted at an environmental temperature of 23°C.

Statistical Analysis

Data were analyzed using repeated measures multivariate analysis of variance (MANOVA). The alpha level was set at 0.05. The rate of rewarming was calculated using the rewarming slope (regression line) of the three rewarming methods.

RESULTS

Cold-water immersion ranged from 40 to 85 minutes (71.1 ± 15.0 min). During immersion, T_{re} and T_{es} initially increased above baseline values in all subjects. After 5 to 15 minutes of cold-water immersion, T_{re} and T_{es} began to decrease. However, at the end of cold-water immersion, T_{re} and T_{es} remained above baseline values in five and three of 18 tests, respectively. T_{re} decreased 1°C in four tests whereas T_{es} decreased in one test (Table 2).

Rewarming Responses

All subjects shivered vigorously during the initial stages of rewarming. However, the intensity of shivering decreased with gradual rewarming of the body. Rewarming for 120 minutes with all three methods was associated with significant ($p<0.01$) and progressive increases in T_{re}, T_{es}, and T_{msk}. As rewarming progressed, $\dot{V}O_2$ decreased significantly ($p<0.01$) in all three rewarming treatments, but no difference between treatments occurred (Fig. 2).

Afterdrop in T_{es} was 0.6 ± 0.3°C with the HHA, 0.8 ± 0.5°C with the HP, and 0.8 ± 0.3°C with the SB. Afterdrop in T_{re} was 0.7 ± 0.4°C with the SB, 0.7 ± 0.2°C with the HHA, and 1.1 ± 0.3°C with the HP (Fig. 3). No significant differences in afterdrop were found among the three rewarming methods in T_{re} or T_{es}.

Analysis of the interaction effect between rewarming time and rewarming method reveals that rewarming occurred faster with HHA compared to HP ($p<0.01$) and SB ($p<0.01$). With the application of the HHA, HP, and SB, T_{es} rewarmed at 1.4°C·hr^{-1}, 1.2°C·hr^{-1}, 1.1°C·hr^{-1} respectively (Fig. 4). With the application of the SB, HHA, and HP, T_{re} rewarmed at 2.0°C·hr^{-1}, 1.6°C·hr^{-1}, and 1.2°C·hr^{-1} respectively (Fig. 5). The application of the SB method rewarmed subjects significantly faster ($p<0.01$) than HP.

With the application of the HHA, SB, and HP, the condition mean for T_{es} was 36.4 ± 0.2°C, 36.3 ± 0.2°C, and 36.3 ± 0.2°C, respectively. The T_{es} with the HHA was higher ($p<0.02$) than with the HP. The T_{es} condition mean for HHA was similar to T_{es} with the SB. With the application of the HHA, SB, and HP, the condition mean for T_{re} was 36.2 ± 0.4°C, 36.1 ± 0.3°C, and 36.0 ± 0.2°C, respectively. The T_{re} with the HHA was higher ($p<0.02$) than the T_{re} with the HP. The T_{re} condition mean for HHA was similar to T_{re} with the SB.

The rewarming rate for T_{msk} was similar among the three rewarming methods (Fig. 6). However, the condition mean for T_{msk} was 32.0 ± 1.4°C for HP, 31.6 ± 0.5°C for HHA, and 30.4 ± 1.2°C for SB; with the HP greater ($p<0.01$) than the SB, and the HHA ($p<0.05$) greater than the SB.

DISCUSSION

This study compared three different strategies applicable to rewarming individuals in the field. Our analysis suggests the HHA is the most effective and safest rewarming method.

Investigators have shown that T_{es} is the more reliable estimation of core temperature (24,25). When using T_{es}, the findings suggest that the HHA rewarmed subjects faster and tended to have a lower (although not significant) afterdrop then either the HP or SB. An unknown portion of this afterdrop occurred prior to commencement of the treatments. Using a larger sample size in future studies may show a significant reduction in afterdrop for T_{es} in these different conditions.

External heating using the HP system significantly increased T_{msk}. However, the external heating appeared to suppress the rise in core temperature as indicated by the changes in T_{re} and T_{es}. The T_{msk} with HHA was higher than with the SB; with the HHA the core temperatures were higher or similar to the temperatures associated with the SB or HP. The HHA warms the skin surface more than the SB, and raises core temperature more than the HP. When significant differences are computed for T_{es}, T_{re}, and T_{msk}, the HHA is either similar or faster at rewarming than the SB or HP. In addition, the treatment for T_{es}, T_{re}, and T_{msk} were similar or higher for the HHA than the SB or HP.

In conclusion, the Heatpac with the Humipac attachment supplying warm, humidified air, may be the preferred rewarming device for use in the field, but further research is necessary.

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Table 1. Physical characteristics of the subjects

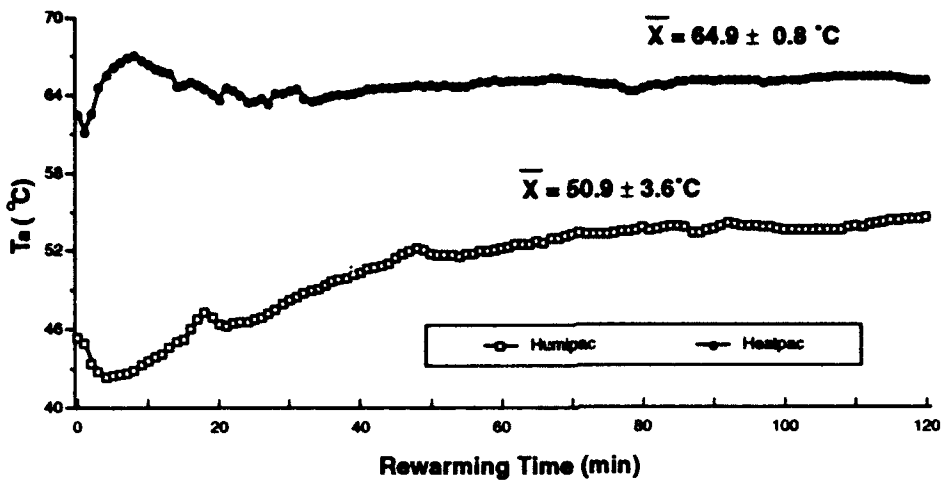
Subject	Age (yrs)	Height (cm)	Weight (kg)	Body Fat (%)
1	34	186.1	93.6	17.6
2	35	170.2	70.6	9.0
3	25	184.2	89.8	23.1
4	35	181.6	89.6	16.9
5	29	168.9	80.6	17.9
6	29	175.9	106.3	24.4
Mean±SD	31±2	177.8±3.0	88.4±4.9	18.1±2.2

Table 2. Baseline to end of immersion changes (n=18 tests)

Measurement	Baseline	End of Immersion	Difference
T_{re} (°C)	37.0 ± 0.2	36.6 ± 0.6	0.4 ± 0.5
T_{es} (°C)	36.8 ± 0.2	36.5 ± 0.6	0.3 ± 0.5
T_{msk} (°C)	29.1 ± 1.1	18.8 ± 1.3	10.4 ± 2.9*
$\dot{V}O_2$ ($l \cdot min^{-1}$)	0.35 ± 0.05	1.08 ± 0.29	0.73 ±0.28*
HR (bpm)	68 ± 10	77 ± 8	9 ± 14

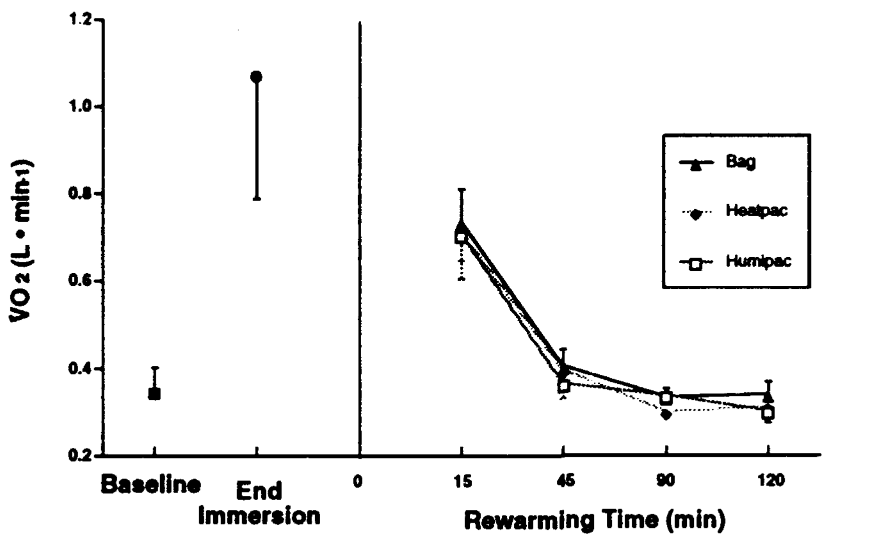
* $p<0.05$

Fig. 1 Heatpac Tentacle and Humipac Near-inspired Air Temperature



Note: Actual inspired air temperature is predicted to be 45.4-47.9°C (authors unpublished data).

Fig. 2 Oxygen Uptake During Three Rewarming Protocols



Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

Fig. 3 Esophageal and Rectal Temperature Afterdrop

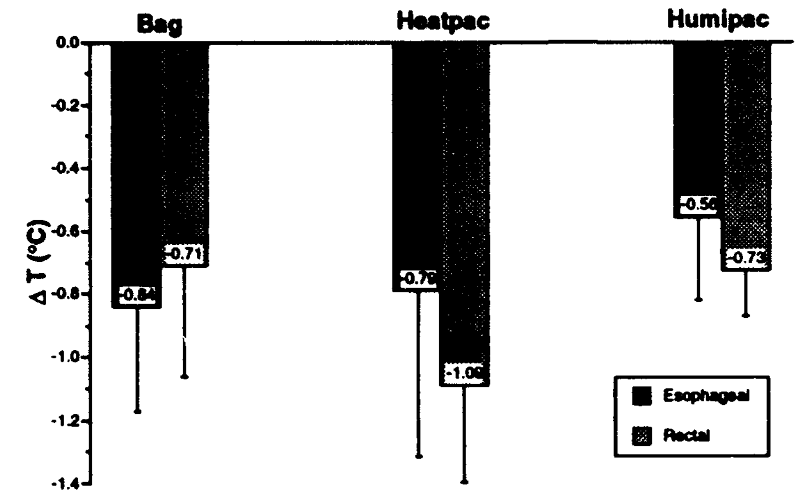
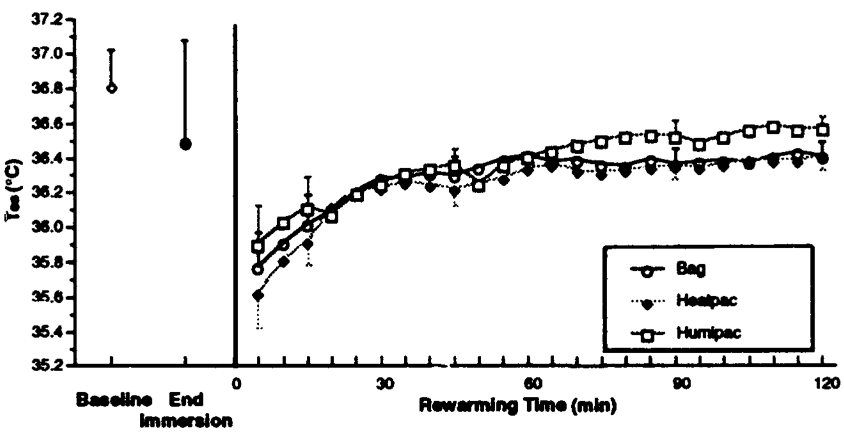
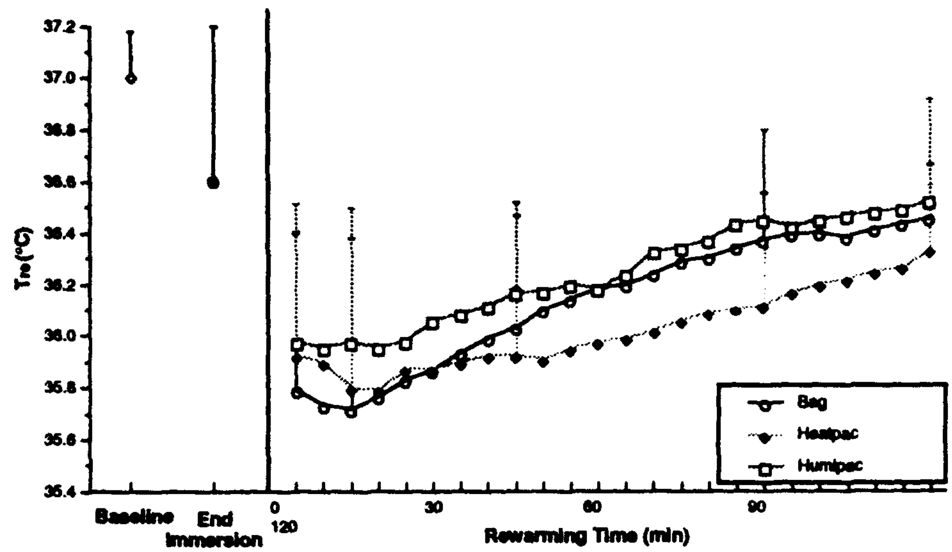


Fig. 4 Mean Esophageal Temperature During Rewarming



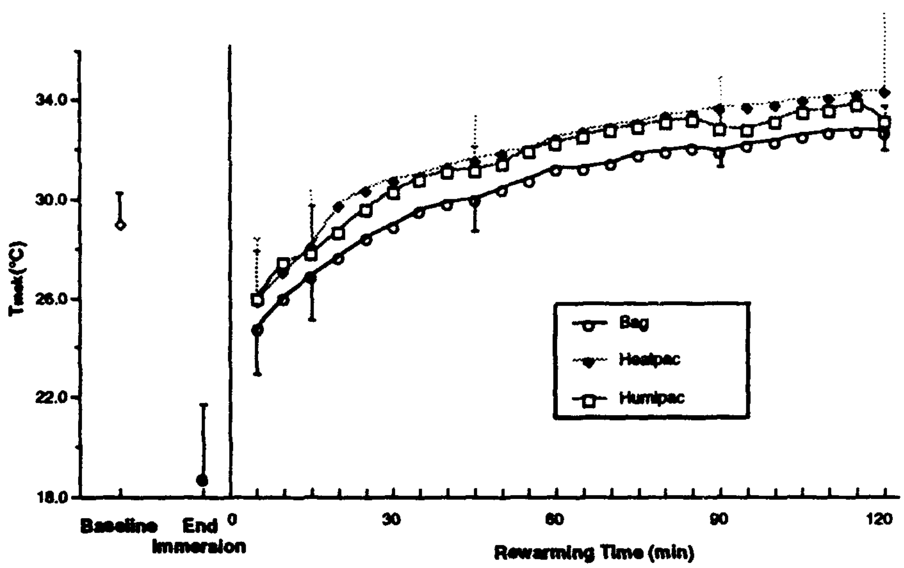
Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

Fig. 5 Mean Rectal Temperature During Rewarming



Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

Fig. 6 Mean Skin Temperature During Rewarming



Note: Baseline and end immersion scores for HHA (n=6), SB (n=6), and HP (n=6) were similar. Baseline and end immersion scores were determined using n=18.

A COMPARISON OF FOUR METHODS OF REWARMING INDIVIDUALS COOLED BY IMMERSION IN COLD WATER

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SUMMARY

It has been suggested that hypothermic individuals could be actively rewarmed in the field by immersion of only the extremities (hands and feet) in hot water. If successful this technique would have enormous potential in the pre-hospital and hospital care of the victims of accidental hypothermia.

The theory is that local heat to the extremities results in opening of the arteriovenous anastomoses with return of warmed blood directly to the core, via the superficial veins, bypassing the intervening cold peripheral tissues.

A comparison of four techniques for rewarming subjects with lowered core temperatures has been undertaken. The techniques examined were: immersion to the neck in water at 40 °C.; immersion of one hand in water at 40 °C.; immersion of two hands plus forearms in water at 42 °C.; passive rewarming. During rewarming core and skin temperatures, heart rate, blood pressure, oxygen consumption and peripheral blood flow were measured at frequent intervals.

No significant difference ($P > 0.05$) was shown in change in core temperature between passive rewarming, immersion of one hand in water at 40 °C or immersion of both hands and arms in water at 42 °C. In the later condition some increase in peripheral blood flow to the hands did occur which may have provided a heat input of 11.8 Watts but any benefit is negated by an associated decrease in intrinsic heat production due to suppression of shivering. Immersion to the neck in hot water was by far the most effective rewarming technique.

It is concluded that hand rewarming, although theoretically attractive, does not work in practice and may even be detrimental in some circumstances, by suppressing intrinsic heat production.

INTRODUCTION

The best method of rewarming victims of accidental hypothermia remains the subject of much debate. Some argue that the rapid restoration of normal or near normal core temperature confers an advantage by minimising the risk of life threatening complications, such as cardiac arrhythmias (1,2), others favour slow spontaneous rewarming which they claim minimises the risk of post rescue collapse (3). The arguments for and against have been extensively reviewed by Golden (4). The method of choice varies according to the state of the victim, the expertise and facilities available and the previous experience of the involved personnel.

Immersion to the neck in hot water (40-42 °C) has proved an efficient and simple method of rewarming conscious victims, but is difficult to achieve in the field and poses major problems to continuous patient monitoring and treatment. More invasive procedures, such as peritoneal or thoraco/pleural lavage with warmed fluids, haemodialysis and cardio-pulmonary bypass, as recommended by the American Heart Association (5), require sophisticated facilities and skilled practitioners. These techniques have no place in the field or in transit. External rewarming with heat sources and blankets has proved inefficient (6).

It has been suggested that hypothermic patients, in the absence of cardiac standstill, could be actively rewarmed by immersion of the extremities (hands and feet) in hot water (7). If successful this technique would have enormous potential in the pre and hospital care of the victims of accidental hypothermia. It would require little or no specialised equipment or expertise and could be utilised in virtually any situation. In addition the torso and proximal limbs would remain available for monitoring, treatment and resuscitation.

The theory underlying this technique is that local heat to the extremities stimulates opening of the arteriovenous anastomoses in the periphery. As a consequence the blood flowing to the periphery is warmed in its passage through the immersed, heated extremity. There is some evidence, from thermographic studies, that warmed blood returns to the core via superficial veins, bypassing cold intervening tissues, and provides warmth directly to the core (8).

The conclusions that underpin the technique, however, arise from data obtained from subjects with undefined or normal core temperatures. It was, therefore, decided to evaluate the technique in a series of experiments in subjects pre-cooled by immersion in cold water.

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In experiments 1, 2 and 4 the value of different hand rewarming techniques was compared with head out immersion in hot water and spontaneous rewarming with the aim of determining where between these two extremes rewarming by hand immersion fell. In experiment 3 the possibility of opening the peripheral vasculature and thereby supplying heat to the core of generally cooled individuals was investigated. Such a response would be essential if profoundly cooled individuals were to benefit from immersion of the limbs in hot water.

METHODS

Four experiments were undertaken involving 19 male and 3 female volunteers, involving a total of 94 immersions.

Subjects:

All the subjects were fully medically examined and gave full written informed consent to the experimental procedure.

	Males:	Females:
	n = 19	n = 3
Mean age:	26 (SD 5)	21 (SD 5)
Mean height	176cm (SD 5)	172cm (SD 4)
Mean weight	82Kg (SD 12.4)	65Kg (SD 8)
Mean fat thickness(9)	17.4% (SD 3.9)	27.8% (SD 2.3)

Experiment one:

Six healthy male subjects were used. Each was cooled, by immersion in cold water at 10 °C, whilst dressed in a dry suit ensemble, on six occasions separated by at least 24 hours (36 immersions). The core temperature of all subjects was lowered, but for ethical reasons was not allowed to fall below 35 °C, measured rectally, before removal from the cold environment. After each immersion the subject was "rewarmed" by one of three methods dictated by the experimental design:

1. Passive external rewarming by wrapping in a padded rescue blanket in a room at 20 °C (20.4, SD 2.26).

2. Active external rewarming by immersion to the neck in a bath of stirred water at 40 °C (39.8, SD 0.35).

3. Active external rewarming by immersion of one hand in a stirred water bath at 40 °C,(40, SD 0.14), whilst wrapped in a padded rescue blanket in a warm room at 20 °C (20.4, SD 2.26).

Each subject was "rewarmed" by each method twice. For each method the subject was naked save for swimming costume and rested in a semi-recumbent position, either in a large insulated bath or on an upholstered couch in the laboratory. The ambient temperature was controlled to 20 °C. Rewarming was continued until the subject's core temperature was rising and he was comfortable. If rewarming was not achieved within a 30 minute period then the procedure was abandoned and the subject was placed in a hot bath until his core temperature was rising and he was comfortable.

Experiment two:

Four different healthy male subjects were cooled as in experiment one, on four occasions each (16 immersions). Following cooling they were "rewarmed" by one of four methods:

1. Active external rewarming by immersion of one hand in a stirred water bath at 40 °C (40.1, SD 0.22) whilst wrapped in a padded rescue blanket in a warm room at 20 °C (20.2, SD 0.68).

2. Active external rewarming by immersion of both hands in stirred water baths at 40 °C (40.1, SD 0.22) whilst wrapped in a padded rescue blanket in a warm room at 20 °C (20.2, SD 0.68).

3. Active external rewarming by immersion to the neck in a bath of stirred water at 40 °C (39.9, SD 0.28).

4. Passive external rewarming by wrapping in a padded rescue blanket in a warm room at 20 °C (20.2, SD 0.68).

Each subject was "rewarmed" by each method once and rewarming was continued to the same end point used in experiment one.

Experiment three:

A further six healthy male and female subjects were used. Each underwent a single seated head-out immersion in stirred water ranging in temperature from 40 to 15 °C.

Following the collection of base line data in air at 20 °C, the subjects were immersed to the mid chest in stirred thermo-neutral water (35.5 °C), in an insulated bath. After the collection of post-immersion data, the water temperature was raised over 5 minutes to 40 °C. The subjects core temperature was allowed to rise by half to one degree, and then cooling was commenced by lowering the bath temperature to 15 °C over 5 minutes.

Cooling was continued for 45 minutes, but at minute 25 both arms were placed, to the elbow, in insulated water baths at 42 °C.

After 45 minutes the water temperature was again raised to 40 °C and rewarming continued until the core temperatures were approaching normal.

Experiment four:

Six different healthy male subjects were cooled as in experiment one, on six occasions each (36 immersions). Following this they were "rewarmed" by one of three methods:

1. Passive external rewarming by wrapping in a padded rescue blanket in a warm room at 20 °C (20.2, SD 1.37).

2. Active external rewarming in a bath of stirred water at 40 °C (40.1, SD 0.35).

3. Active external rewarming by immersion of both hands and forearms in stirred water baths at 42 °C (42.1, SD 0.25), whilst wrapped in a padded rescue blanket in a warm room at 20 °C (20.2, SD 1.37).

Each subject was "rewarmed" by each method twice and rewarming was continued until the core temperature was rising and the subject comfortable. If rewarming was not achieved within one hour then the procedure was abandoned and rewarming in a hot bath substituted.

Physiological variables monitored:

The physical characteristics of each subject were measured - naked weight, age, height and skin fold thickness measured at four sites using callipers (9).

The following physiological variables were monitored during the course of the experiments:

Heart rate - from a continuously recorded 3 lead ECG (Tektronix 408 Monitor, Beaverton, OR, USA; Gould 2600S, Ohio, USA).

Core temperature - measured using a rectal thermistor (accurate to 0.04 °C) inserted 15 cm beyond the anal margin and an aural thermistor (accurate to 0.04 °C) insulated and secured close to the tympanic membrane. Both were recorded every minute (Squirrel Data Logger, Grant Instruments, Cambridge, UK). In addition in experiment three a gastric telemetry pill thermistor was used and data recorded every five minutes.

Skin temperature - measured by skin thermistors attached by a single piece of tape to nine sites: Forehead; Chest - 5cm above the right nipple; Forearm - 5cm proximal and midway between the radial styloid and the ulna styloid; Centre of the back; Abdomen; Mid right buttock; Mid front of thigh; Mid back of thigh; Mid calf. All temperatures were recorded every minute on a data logger (Grant Instruments, Cambridge, UK). In experiment three only four sites were used: Forehead; Chest; Hand; Foot.

Blood pressure - measured non-invasively by oscillometry via a cuff placed on the left upper arm (Dinamap 845, Applied Medical Research, Florida, USA), and recorded every five minutes

Digital blood flow - measured, qualitatively, by infra-red photo-plethysmography from transducers placed on the pulps of both thumbs and recorded continuously on a two channel recorder (Vasculab PPG13, PH77 sensors, R12B recorder, Medasonics, California, USA).

Oxygen consumption - calculated by analysis of pneumotachograph volumes and mixed oxygen and carbon dioxide concentrations recorded continuously from a mixing box placed on the expiratory side of a mouthpiece assembly. Values were calculated from data recorded at five minute intervals throughout the experiment (Gould 2600S Recorder, Ohio, USA).

In experiment four, only, thermal comfort was assessed using a linear analogue scale and recorded every five minutes.

Materials:

The rescue blanket used in all experiments was Nylon covered, of quilted construction, and filled with two layers of shredded metal foil separated by cloth wadding.

The rewarming bath was insulated and stirred by a circulating pump. The water temperature was controlled, by a fully automatic biomechanical Tipton Valve, and monitored by three thermistors spaced at points along its' length.

The hand baths were insulated containers supplied from a thermostatically controlled heating reservoir by a mixing/circulating system (Cahill). The temperature was monitored continuously in all three tanks in the system. In experiment three the containers were placed, partially submerged, on either side of the subject in the insulated bath.

RESULTS

Analysis of the data was performed by repeated measures ANOVA. All results are quoted at the 5% level of significance unless stated otherwise.

In all experiments the aural temperature data, and in experiment three the gastric telemetry pill data, supported the rectal temperature data, therefore, only this data is quoted.

In experiments one, two and four immersion to the neck in hot water was seen to effect rapid rewarming of all the subjects within 30 minutes and in most instances within 20 minutes. Rapid and progressive vasodilatation, to maximum vasodilatation, occurred with increasing IR plethysmograph amplitude, falling diastolic blood pressure and increasing heart rate. Following a short lived afterdrop, the core temperature was seen to rise rapidly at a constant rate, (Fig 1). The procedure was discontinued when the subject began to feel uncomfortably hot which corresponded with a rising core temperature of approximately 36.5 °C.

In experiment one, comparison of passive rewarming and active rewarming by immersion of one hand in hot water demonstrated no significant difference between the techniques. In both conditions the core temperature remained constant or fell gradually over the 30 minute period, (Fig 2). Heart rate fell to low levels (mean 53.84, SD 4.51), diastolic blood pressure remained high (mean 92.81, SD 8.71), and there was no evidence of increased digital blood flow even in the hands immersed in hot water.

Similarly, in experiment two, there was no significant difference between passive rewarming and active rewarming by immersion of one or two hands. Again the core temperature remained constant or fell a little gradually over the 30 minute period. The physiological variables showed the same changes as in experiment one. An impression was gained that the gradual fall in core temperature was more marked in the hand immersed conditions. In all conditions the subjects were comfortable and feeling "warmer" at the end of 30 minutes despite their lowered and falling core temperatures.

In experiment three, the immersion of both hands and arms in hot water during cooling of the subjects resulted in a increase in the rate of cooling, (Fig 3). The rate of fall of average rectal temperature in the ten minutes before immersion of the hands (15 to 25 minutes) being 0.6 $°C.h^{-1}$, and after immersion of the hands (35 to 45 minutes, once the new rate of cooling had been established) being 1.5 °C. There was no increase in digital blood flow with immersion in hot water whilst cooling was in progress.

In experiment four, comparison of passive rewarming with active rewarming by immersion of both hands and arms in hot water showed a slight increase in digital perfusion in the hands-in condition. There was an initial increase within 5 minutes followed by a fall and then a further increase from 15 minutes onwards. Although the plethysmograph amplitudes were significantly higher compared with the passive condition, at no time did they approach those seen in full vasodilatation associated with bath rewarming, (Fig 4). Only one subject rewarmed during the 60 minute period but did so equally in the passive and passive plus hand in condition. The others all experienced a fall in core temperature and there was no significant difference between the two conditions, in either absolute values or rate of change in temperature, (Fig 5). Heart rate remained low, but there was a gradual increase in the hands in condition resulting in significantly higher rates at the end of the experiment. Diastolic blood pressures were normal to high in both conditions and there was no significant difference between the values in the conditions by the end of the experiment. Oxygen consumption was consistently lower in the hands in condition after 10 minutes. On average, from 10 to 60 minutes, 2.1 litres less oxygen was consumed in this condition, this is equivalent to 42.4 K Joules less heat production.

DISCUSSION

The concept of rewarming victims of accidental hypothermia by hand and/or foot immersion in hot water appears very attractive, with potential to be of major benefit in emergency medicine. This prompted the reported series of experiments.

The initial experiments demonstrated no significant benefit to the technique during the first 30 minutes after removal from the cold environment, over wrapping in an efficient insulating blanket. The act of immersing one or two hands in water at 40 degrees C did make the subjects feel a little "warmer and more comfortable" but appeared to, if anything, inhibit intrinsic heat production by shivering. This hypothesis was strengthened by the data from experiment three. Vanggaard and Gjerloff (1979) reported that the fall in deep body temperature, caused by immersion to the neck in water at 15 degrees C, could be nearly stopped by exposing the hands to circulating water at 45 degrees. Their experiment was repeated, however, the subjects could not tolerate placing their hands in water hotter than 42 degrees C. At this temperature, despite the subjects having the forearms immersed also, the rate of cooling was accelerated. The subjects experienced an increase in thermal comfort subjectively and were noted to stop shivering or to shiver less vigorously.

During the first two experiments the "rewarming" period was short and only one or both hands (approximately 3 or 6% total body surface area respectively) were immersed. It was decided to increase the area immersed to both hands and forearms (approximately 12% TBSA) and increase the water bath temperatures to 42 degrees (maximum temperature tolerated by subjects) for experiment four. These changes did not produce any significant differences in core rewarming, although some increase in digital skin blood flow was seen,as measured by IR plethysmography. The increases in plethysmograph amplitudes were sub-maximal compared with those seen

in bath rewarming. The increase in plethysmograph amplitudes is supported by the increase in heart rate in the hands in condition and suggests an increase in peripheral blood flow, however, the decrease in oxygen consumption caused by heating the immersed area to 42 °C appeared to counter any advantage gained. If it is assumed that, as the core temperatures did not differ between conditions, the decreased heat production was balanced by heat from the hands, then the theoretical maximum heat gain from hand immersion in the condition of experiment four was 11.8 Watts. This is a very rough approximation which includes several assumptions, but does give an indication of the heat which might be gained from the arms. These figures contrast with the 198 Watts which can be lost by cold immersion of the hands of individuals who are maximally vasodilated as a result of exposure to heat (10). It is believed that any local influence on peripheral vasomotor tone is overridden by centrally mediated vasoconstriction due to low and/or falling core temperature. This overriding central stimulus would have been greater in experiment three where active cooling continued, which explains why no increase in digital skin blood flow was seen despite the hand bath temperatures being at 42 degrees, in these subjects.

The data was obtained from subjects with defined, lowered core temperatures but due to ethical considerations it was not possible to lower temperatures to hypothermic levels (less than 35 degrees C). It is possible that an alteration in the central control of peripheral blood flow may occur at lower core temperatures which would allow larger increases in locally stimulated limb blood flow, but it is believed that there is insufficient transport of heat to the core to significantly accelerate rewarming and that the associated suppression of intrinsic heat production is detrimental to rewarming.

CONCLUSION

Previous experimental work on active external rewarming by the immersion of the hands has been undertaken on subjects with normal or unspecified core temperatures. For hand rewarming to be of benefit in the treatment of victims of accidental hypothermia it must be shown that the peripheral vasculature can be opened and the extremities perfused when the core temperature is below normal. The results of the studies undertaken within the present investigation suggest that if this does occur the levels achieved are insignificant.

It is therefore concluded that hand rewarming, although theoretically attractive, does not work in practice and may even be detrimental in some circumstances, by suppressing intrinsic heat production.

ACKNOWLEDGEMENTS

The authors acknowledge the efforts of the subjects, the invaluable advice of Surgeon Rear Admiral F StC Golden Royal Navy, the technical expertise of Mr P Moncaster, Dr R Pethybridge for his help with the statistics and the assistance of the staff of the Institute of Naval Medicine. The support of the Research Funds of the Royal Naval Hospitals HASLAR and PLYMOUTH is gratefully acknowledged.

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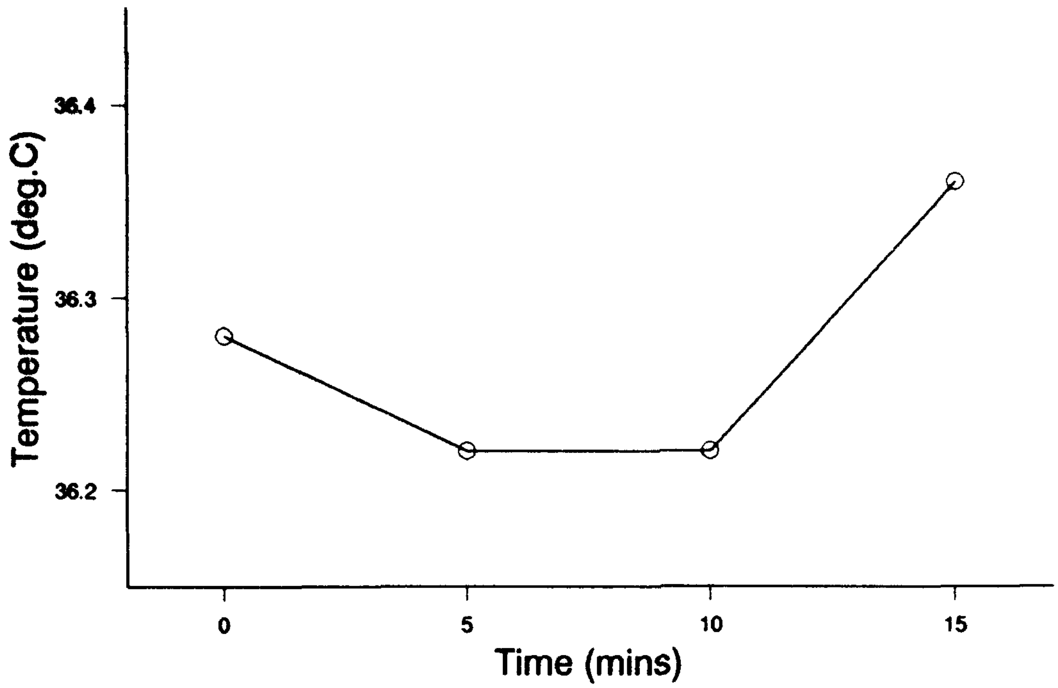
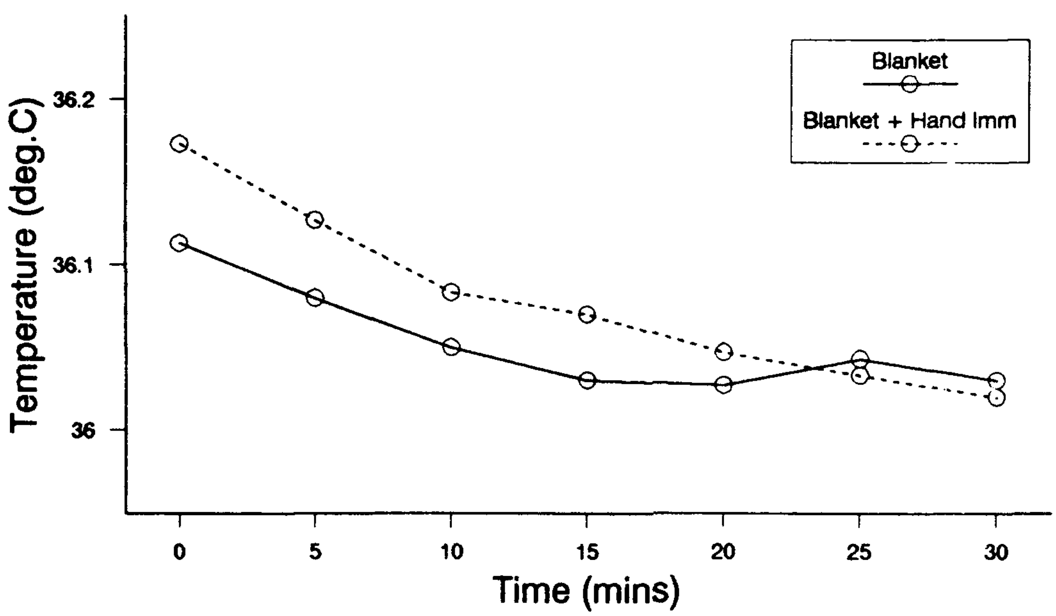
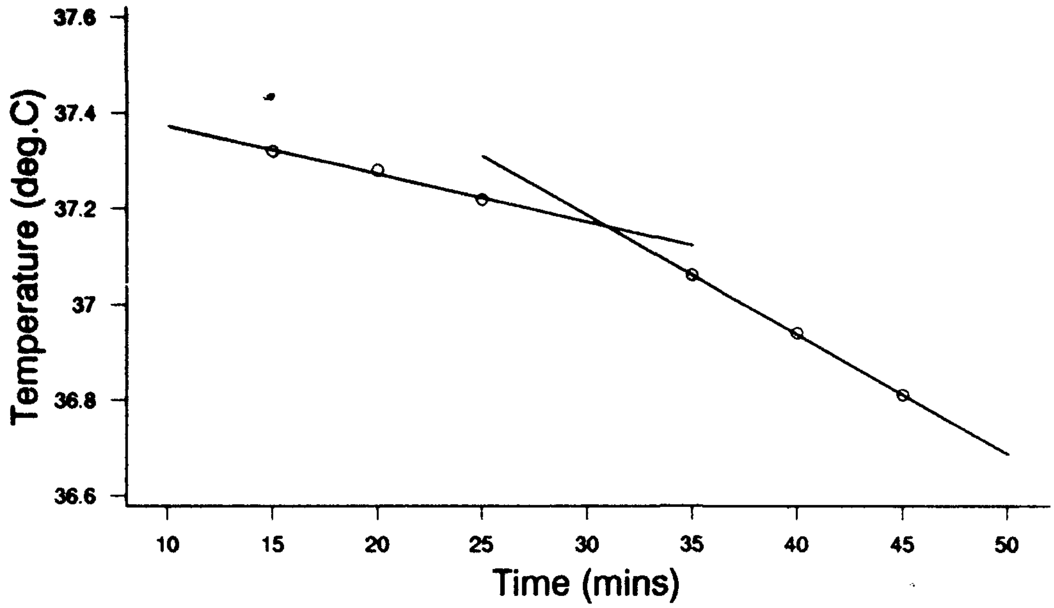


Fig. 1. Average rectal temperature during rewarming by immersion in hot water (n=12)



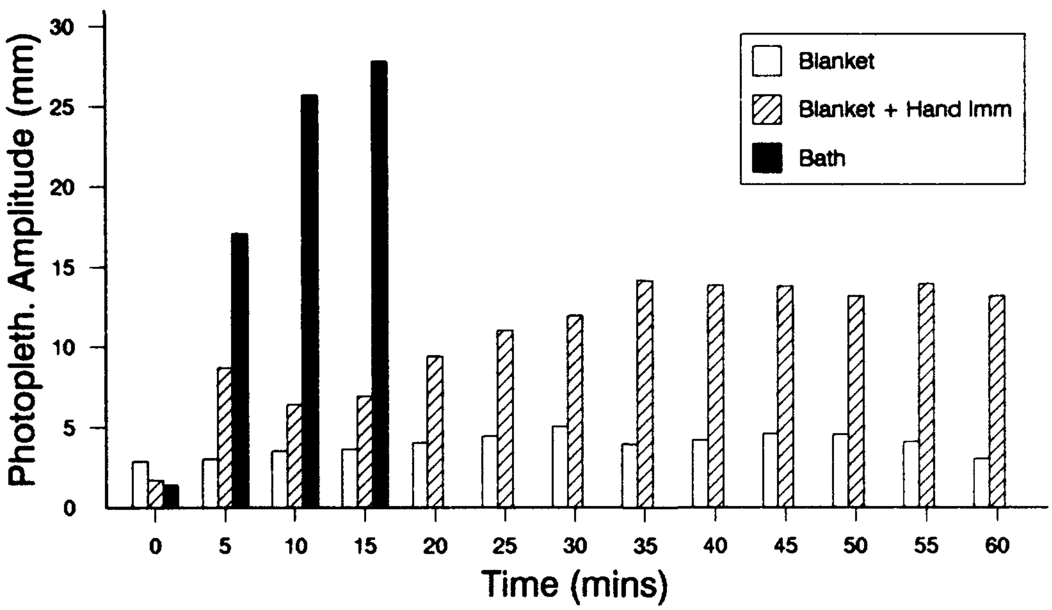
Hand immersion: one hand, Tw 40 deg.C

Fig. 2. Average rectal temperature during rewarming following cooling in cold water (Experiment 1, n=6)



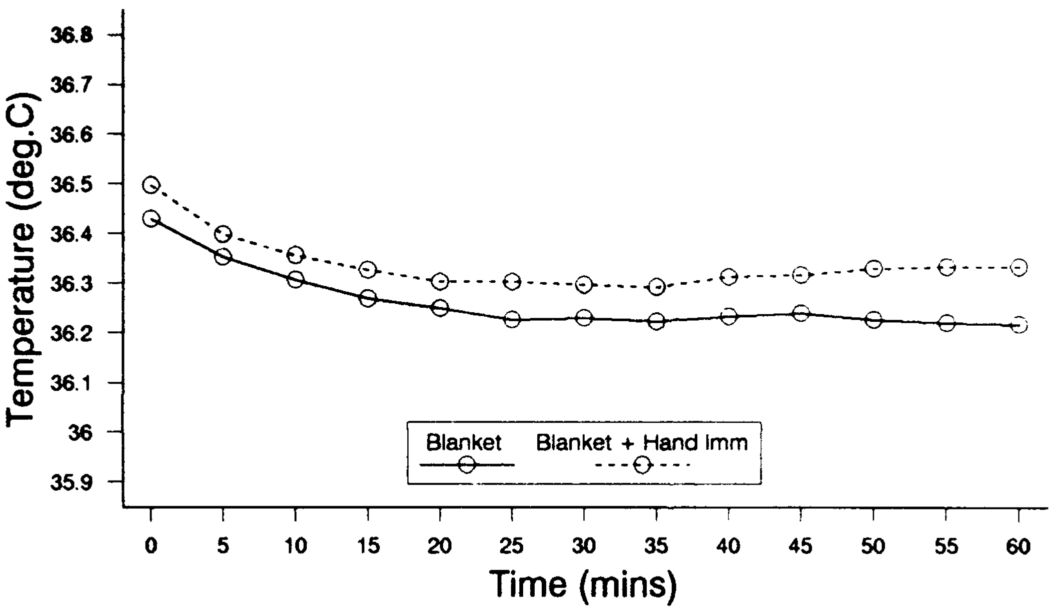
Arms immersed at 25 mins into water (Tw 42 C)

Fig 3. Average rectal temperature during immersion in cold water with and without hand and forearm heating (Experiment 3, n=6)



Hand immersion: both hands/forearms, Tw 42 deg.C

Fig 4. Average photoplethysmograph amplitudes during rewarming following cooling in cold water (Experiment 3, n=6)



Hand immersion: both arms/forearms, Tw 42 deg.C

Fig 5. Average rectal temperatures during rewarming following cooling in cold water (Experiment 3, n=6)

KEYNOTE ADDRESS 2

MEDICAL SUPPORT OF ATTACK HELICOPTER BATTALIONS DURING THE GULF WAR

by

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SUMMARY

This purpose of this presentation is to describe the medical support that was provided to the Apache Attack Helicopter battalions during Desert Shield and Desert Storm, to describe some medical problems associated with the deployment in this environment, and to suggest areas that might be fruitful for further study or research.

INTRODUCTION

Probably the most important factor related to decreasing casualties in a war is winning it (1). While this axiom makes intuitive sense to commanders and soldiers, it seems to make many military medical personnel uncomfortable; it is none the less true. It logically follows that medical planners, practitioners, and especially researchers must recognize that their ultimate responsibility is to enhance the commanders' ability to prosecute the war successfully. They must first understand the mission of the type unit they plan to support, and the resources available (in terms of personnel, weight, cost, space requirements etc) in order to be successful.

The Army has generic medical support plans for all size units, from platoon to corps level(2). Basically, battalion level medical support consists of an aid station, stocked with first aid and general medical supplies, and staffed by a physician or physician's assistant. The aid station may be physically located in a tent, the back of a truck, or a building, depending on the type of unit (aviation, infantry, armor or other) and environment. Enlisted medics may be assigned individually to companies or platoons to provide initial casualty treatment, and evacuation to the aid station if required, or they may work in the aid station itself. In general, the aid station is located in the battalion rear area, and forward deployed medics bring the sick and wounded soldiers to the aid station. Doctrinally, further evacuation to the rear will be provided by higher level evacuation coming forward to pickup casualties.

Aviation battalions, especially attack helicopter battalions, are unique among Army units. Numerically, they are much smaller than ground units, having less than 300 people assigned. For short periods of time, they are expected to be able to deploy independently of the rest of the brigade or Division, with their own fuel, ammunition, communication and of course, medical support. Because the unit moves by very disparate means (ie, aircraft and wheeled vehicles) it does not move as a

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unit; the 35-40 aircraft can easily outdistance the 100 trucks and trailers by several days. During movement, there must be some level of medical support in at least two major locations, as well as at remote forward arming and refueling points (FARPs). The distance factor is even more significant during deep attack missions. In some ways, Apache helicopter procedures are more similar to Air Force than traditional Army maneuvering. With their auxiliary tank capability, they can fly hundreds of miles, perform their attack missions, and fly home without refueling. Use of the FARP extends their potential range even further, making them very different from Infantry or Armor units, in which distances may be measured in yards. Search and rescue and medical support must be available on site at the time of any crash (whether enemy anti-aircraft weaponry, mechanical or pilot induced) that may occur during these extended missions if we hope to bring these aircrew back safely.

DESERT SHIELD/DESERT STORM

As the surgeon for the 2/229 Attack Helicopter Battalion throughout Desert Shield and Desert Storm, I was responsible for the preventive medicine, emergency medical care, medical evacuation, and medical education of all personnel in the battalion. Five enlisted medics, a two and a half ton truck, a pickup truck and trailer, and whatever we could load on them, comprised our medical facilities. When the rest of the 101st Aviation Brigade arrived, I was appointed the brigade Preventive Medicine Officer, and provided medical care to units that lacked a battalion surgeon. During the initial weeks, the individual squadron and battalion surgeons of the Apache and A-10 units at King Fahd (eastern Saudi Arabia) airport devised a local, multi-service mass casualty plan, as there were no United States military hospital readily available. Later, we participated in the 101st Division, and two Air Force Wing mass casualty plans.

Throughout the deployment, until the war actually started, the biggest challenge was education: of commanders, soldiers, and medical personnel. Commanders are essentially ignorant of medical matters, the Army Field Manual covering Attack Helicopter operations (3) has exactly one paragraph devoted to medical support of the battalion. As a member of the commander's staff, the surgeon had to be aware of the battle plans, plan to allocate medical assets to support the plans, and explain the medical consequences of alternate courses of action. The flight surgeons were instrumental in developing decontamination procedures that would be useful for personnel, wheeled vehicles and aircraft as safely as possible. Soldiers will perform better when their fear and ignorance are replaced with knowledge. They needed education to understand the rudiments of buddy care, the rational of chemical weapon prophylaxis and treatment, and their own responsibilities for health maintenance. From the medical standpoint, it was a significant challenge to

educate the medics that despite being in an unfamiliar and exotic location (with extreme environmental conditions), most medical problems were the same as those encountered in more familiar territory. But even though the medical problems were often identical, treatment had to be tailored to what was available in terms of supplies and equipment, and practical based on the living conditions.

There were concrete examples of this phenomenon almost daily. A young sergeant presented with fever and severe headache. He had been seen daily by another practitioner for the past three days; each time the diagnosis was apparently "heat and dehydration" because he was given several liters of intravenous (IV) fluid and told to rest and drink more. On the third day, his commander brought him to me because he was getting worse. The man did indeed have a fever (104 F/40 C) and a severe headache. He also had a normal pulse, his blood pressure was high normal, and his headache was unilateral and worse when lying down. The only IV antibiotics at the aid station were ampicillin and rocephin, but after two doses of IV ampicillin, he was afebrile and his headache was resolving. The message was twofold: first, all the fluid in the world will not cure sinusitis; and second, that living in Saudi Arabia does not prevent it!

On another occasion, after a two week training deployment in December, essentially every pilot in one of the attack companies developed severe nausea, diarrhea, headache and fever of 103-105 F/ 39-41 C. The etiology was never determined, but I treated them all with aspirin and acetaminophen for fever and pain, Septra for presumed Shigella or Salmonellosis, phenergan for nausea, and lomotil for the diarrhea. This does not meet the usual "standard of care", because antidiarrheal medication may actually extend the duration of the illness, and we don't usually treat with antibiotics without a positive stool culture. It is important to recognize the absolute austerity of the conditions: we were living in an open parking garage, and the only latrine facilities were 55 gallon drums cut in half, located outside a barbed wire perimeter several hundred meters away. Without the antidiarrheal medication, they would physically never have made it, or would have been forced to spend several days perched on the side of an oil drum in sub freezing weather.

We did, however, encounter a number of problems unique to living and working in the harsh environment. On the day we arrived, 21 August 1990, it was 138 F/59 C on the flight line. We unloaded the aircraft, and began reconstituting our combat capability, ie, reassembling the helicopters. It was absolutely impossible during the day, not only could the unacclimated troops do nothing more than sleep in the unfamiliar environment, but the temperature of the aircraft parts themselves made working on them dangerous. Neither natural shade nor hangers were available, and neither flight gloves nor leather work gloves

provided sufficient insulation from the metal parts exposed to the Saudi sun. This proved to be a continuing problem; preflighting an aircraft was painful, and even flying, simply holding the controls of an aircraft that has been in the sun was very difficult. Taking bottled water on missions was essential to prevent dehydration, but leaving it in the aircraft resulted in water that was not only too hot to drink, but actually burned if poured or spilled on skin. As expected, aircrew were inventive; they procured aluminum foil from the cooks to fashion reflective shields for their cockpit surfaces. This helped considerably, but would not have been acceptable had hostilities begun during the early months, as these "reflective shields" would have served as huge signal mirrors to any hostile reconnaissance aircraft. To maintain water at reasonable temperatures, we adopted measures like the bedouins use, wrapping canteens and water bottles in cloth, and keeping them wet to allow evaporative cooling.

The uniquely medical problems were not insignificant. Many drugs must be stored at or below "room temperature", but there is no indication how fast the biological activity degrades at ambient temperatures of 100-140 F/38-60 C, nor what duration the exposure must be before degradation occurs. Even sterile IV fluid must be kept "cool" to ensure its shelf life, as well as to make it valuable therapy for hyperthermia and dehydration. Infusing large quantities of 110 F/43 C fluid would not have been particularly beneficial! While I had planned for the heat, and brought two small refrigerators specifically for medical supplies, generators were required, and not available consistently. For these situations, we procured five gallon coolers, and purchased ice locally to transport our most vulnerable medical supplies.

Immediately before deploying in August, I gave lectures on how to prevent heat injuries, and the importance of early recognition and treatment. Apparently the prevention education program worked; although a substantial number of soldiers presented with dehydration (decreased BP, increased pulse, weakness, headache and "dizziness"), none were hyperthermic by oral or rectal temperature. During the first weeks, we were exceptionally aggressive about rehydrating people with intravenous as opposed to oral fluids. This served at least three purposes. First, a satisfactory clinical response could be accomplished in a shorter period of time. Second, it gave the medics a superb opportunity to become expert at starting IV lines when time was less critical than it would be later, caring for hemodynamically unstable casualties. Lastly, knowing that the therapy for dehydration would be a stick with a large bore catheter, encouraged soldiers to drink sufficient quantities, regardless of thirst or palatability.

As we deployed to combat in January, there was more rain

than in the previous ten years, making driving or flying both slow and hazardous. While there is no question that the cold environment was not as extreme as the heat had been, it was very extreme to troops who were not prepared for cold in terms of clothing, training, or equipment. As described previously, the aircraft (and aircrew) generally moved separately, ahead or behind the truck convoys. The tents, cooking equipment, and majority of medical supplies were always in these convoys. The Blackhawk (UH-60) aircraft are designed for cargo, and their crews always had tents, a generator, kerosene stoves and other gear with them to make the sub zero conditions tolerable. Pilots of the Apaches and scouts were less fortunate; unless the trucks caught up with the aircraft, they slept on the ground or in their cockpits, eating cold MREs, until the main body of the unit arrived. I always moved by air, and had equipped all three Blackhawks with a few litters, extra old sleeping bags, and a chest of emergency medical supplies. Even before actual combat there were several occasions that our utility (ie, non medevac) Blackhawks were the first on the scene of an accident. It was lifesaving to be prepared for either motor vehicle or aircraft accidents. Later, when performing actual attack missions, one of the Blackhawks always followed a few kilometers behind the Apaches to provide immediate search and rescue in case of a crash or shoot down. Insulated bags (actually designed to carry 20 gallon coffee containers), were used to carry IV fluid; before departing on missions we would insert chemical heating pads to keep the fluid warm. The medics moved by trucks, which were usually split into three separate convoys in case of attack, so one or two medics traveled with each group. It proved to be essential; on every move there was an accident or incident that required medical assistance.

Despite well founded concerns over deployment to the unfamiliar Saudi Arabian peninsula, I am unaware of any actual "environmental casualties" within the 101st Aviation Brigade that were sufficiently serious to warrant evacuation to any higher level medical facility than a battalion aid station. Although there were certainly environmental injuries: dehydration, heat exhaustion, and sunburn due to heat, hypothermia due to rain and cold exposure, and corneal abrasions from sandstorms, all were treated and returned to duty within hours. The injuries (and deaths) requiring evacuation: motor vehicle and aircraft accidents, gunshot wounds, anti-personnel mine explosions, burns, and various occupational and sports injuries, would have occurred in any theatre of operation, they were not unique to the Gulf conflict. Additionally, there were numerous illnesses requiring evacuation, (either to fixed facilities within the theater, or back to the United States), but these could not be blamed on the harsh environment either; there were a few suicide gestures and other psychiatric disorders, a questionable case of unstable angina versus delirium tremens

from the unavailability of alcohol, one non-traumatic spinal cord lesion, and several inguinal hernia repairs.

What did I, the senior medic, spend the majority of my time doing? In actuality, probably personnel and personal issues. Trying to track the progress of soldiers who had been evacuated; the medical system considers them generic patients once they enter the evacuation system, but the commander still considers them "his" soldiers. He wants to know their whereabouts, progress, and anticipated return; only a medical officer is able to navigate the evacuation and medical channels. Procuring medical supplies required more than simply filling out requisitions, we had to find someone who had what we needed, and convince them to "share". Helping soldiers in the unit get through the paperwork in order to return home for funerals or other emergencies took alot of time; it is certainly not a medical function, but the soldiers trust the flight surgeon, and maintaining their trust is paramount. Working through family issues (spouses writing "Dear John" letters for example), problems with other members of the unit, and reassuring them through the fear and uncertainty that most service members feel waiting for combat, these occupied the majority of hours. The time spent physically performing first aid, minor surgery, diagnostic procedures, accident investigations and medical evacuation was in fact a small percentage of an average day.

CONCLUSION

Despite the harsh, unfamiliar conditions encountered by U. S. Army aviation units during Desert Shield and Desert Storm, there were minimal environmental casualties. This may have been due to the relatively young, healthy population comprising the military, as well as good training and understanding of the environmental threats. I believe greater research efforts should be directed towards solving problems of units deployed under austere conditions. Self warming "body bags" for casualty transportation, longer lasting chemical hot and cold packs, there are any number of fruitful avenues of research that would be useful to Army aviation units. Extending the shelf life of pharmacologic agents exposed to environmental extremes, increasing the palatability of field rations, decreasing the heat burden of chemical protective clothing, or developing more heat resistant glove material, for example, are problems that are relevant to aviation units that do not have fixed facilities, with their attendant luxuries of electricity, air conditioning or running water. It seems unlikely that the living conditions of the battle will change appreciably for Army aviators of the future; life in Saudi Arabia was much like life "in the field" has always been. It is up to us, the medical community of practitioners, planners, and researchers, to support that Army aviator to give him the best possible chance of accomplishing the mission.

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Aeromedical Support for Casualties in Extremely Hot Climates

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1. SUMMARY

Aeromedical support for operations in hot climates involves exposure to acute heat injury and chronic heat stress which are unfamiliar to many medical personnel in NATO nations. Preparation for deployment to a hot climate should include review of climatic data for the site, appropriate adjustment to supplies and equipment needed to handle predicted numbers of heat casualties, and education of all air base personnel regarding methods of preventing heat illness. Medical facilities at the remote site may include local buildings or air transportable units. Special care is required with respect to housekeeping and provision of safe food and water in hot climates. Casualties arriving from remote sites should be assumed to suffer from heat stress and dehydration; those with elevated temperatures or disturbed consciousness must be treated as heat stroke cases until proven otherwise. Oral rehydration mixtures should be used whenever possible, reserving intravenous fluids for severe cases. Plans for air evacuation of all patients should attempt to minimize heat stress during loading and allow for continued rehydration in flight.

2. INTRODUCTION

Heat illness develops in the presence of heat-induced dehydration, cardiovascular decompensation, and/or an injurious rise in body temperature. Symptoms range from subtly impaired performance to frank illness, incapacitation and death. Military operations in desert or tropical climates can involve a high incidence of primary heat injury cases as well as significant numbers of heat-related disorders in casualties of other types. In addition, continuous heat stress increases fluid requirements and produces chronic fatigue and loss of appetite affecting patients, medical staff and air base personnel.

The combination of heat stress and trauma with limited treatment resources is not commonly encountered at medical training centers in temperate climates. Aeromedical personnel supporting operations in hot climates may find themselves with responsibilities ranging from implementation of protective measures for air crew members and maintenance personnel to treatment of frank heat casualties among combat forces. The importance of effective prevention cannot be overemphasized, as heat stroke is equivalent to major wounding and is associated with a high fatality rate (1). Heat stroke survivors are lost to further service for periods of weeks to months and may never again be fit for duty under hot conditions (2).

The authors are developing written materials to assist aeromedical personnel in handling the unaccustomed climatic extremes and suboptimal hospital conditions which they may encounter upon deployment to hot climates.

3. HEAT STRESS AND ITS EFFECTS

Heat stress occurs when some combination of climate, activity and clothing causes body heat load to reach or exceed heat dissipation to the environment. Military operations often amplify climatic heat stress by demanding sustained physical work under very hot conditions. Problems may also develop in relatively cool weather when personnel must wear protective clothing which interferes with convective cooling and the evaporation of sweat. Chemical defense patient-wraps pose a potentially serious heat stress problem in hot climates. Another highly provocative condition is work in sun-heated, enclosed spaces such as parked aircraft, workshops or tents.

Response to a given thermal stress varies widely among individuals and from one day to the next. Heat tolerance is greatest among personnel who are physically fit and are already acclimatized to heat. Although there is no gender difference *per se*, small body size and low aerobic capacity are risk factors for either sex. Other risk factors include lack of acclimatization, intercurrent illness, dehydration, nutritional deficit and cumulative fatigue. Heat stress effects are significantly lowered when there is periodic relief such as retreat to air-conditioned quarters or a strong nocturnal temperature drop.

Adequate water intake becomes critical in hot conditions because evaporation of sweat is the main path for dissipating body heat and the

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only cooling mechanism when air temperature exceeds body temperature. Daily fluid requirements increase dramatically with work and climatic heat load; Fig. 1 shows that even persons resting in the shade may require several liters of fluid per day.

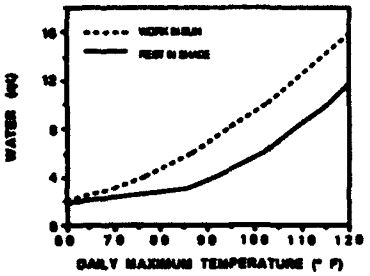

Fig. 1. Daily water requirement from Adolph EF, et al. Physiology of Man in the Desert. New York: Interscience. 1947, p. 121. 1 qt = 0.946 L.

Aircrew members require special consideration because even moderate heat stress can impair their performance enough to tip the balance toward mission failure or even loss of an aircraft. Preventive measures for flying personnel are detailed elsewhere and include protection from preflight heat stress and scheduling which allows for heat-induced fatigue. Inflight heat stress is worst for missions which involve low-level flight and/or evasive maneuvers. Aircrew members should be warned that heat and dehydration reduce acceleration tolerance by 0.5-1 G and increase susceptibility to decompression sickness.

4. PREPARING FOR DEPLOYMENT

Aeromedical personnel preparing for deployment in support of hot-weather operations should review authoritative summaries of preventive measures (3,4) and treatment of heat casualties (5,6).
Liaison should be established with flying personnel and support services to educate all with respect to the special challenges of operating in extremely hot weather. The incidence of heat casualties will depend not only on weather but also on the concept of operations and the possibility of protective modifications such as scheduling work at night. Use of NBC clothing can produce heat casualties even in temperate climates. It is therefore extremely important that aeromedical personnel work with commanders to help them understand the potentially critical impact of heat stress, the beneficial role of acclimatization, and the fact that humans cannot function without adequate water intake.

Every effort should be made to obtain detailed climatic data for the deployment site. Desert regions are often characterized by stable weather patterns with very hot daytime temperatures and cold nights due to radiation cooling. Paradoxically, desert shores can be very humid. Tropical conditions usually involve continuous heat stress with high humidity. Potential sources of site-specific information include base weather offices and central meteorology data banks. The following data should be obtained for each month throughout the year:

- Mean daily high and low air temperatures
- Distribution of daily high and low temperatures (percentile values or ranges)
- Mean wet bulb temperatures or dewpoints corresponding to known air temperature readings
- Mean daily high and low values for Wet Bulb Globe Temperature (WBGT) or other indices
- Wind and cloud cover information
- Times of sunrise and sunset

It is not adequate to have mean daily temperature alone or humidity data without associated temperature readings. If the only available information comes from atlases or country summaries, data must be interpreted with respect to local conditions such as the altitude of the air base or proximity to large bodies of water. Regular communication with the nearest meteorological office should be set up to keep personnel apprised of current and predicted weather conditions.
Before departure, medical personnel should familiarize themselves with organizational responsibility for water supply, food and shelter together with possible sources of ancillary equipment such as generators, fans, air conditioners, refrigerators and freezers. Additional preparations for handling large numbers of heat casualties include:

- Adjust stockage of supplies to allow for heavy use of oral and intravenous fluids
- Obtain thermometers to measure rectal temperature to 45 °C (113 °F)

- Plan for special heat stroke cooling stations with water, ice, fans and life support equipment

Extraordinary measures may be required where the normal supply system cannot provide rapid modification to the Table of Allowances (TA). The first USAF aircrew members deployed to the Persian Gulf carried intravenous solutions and administration sets in their personal kit. If oral rehydration mixtures are not included in medical supplies, the following mixture can be used: To one liter (quart) of water add 40 grams of table sugar and 6 grams of table salt.

5. MEDICAL FACILITIES

Patient care areas and staff quarters in hot climates should be situated to minimize heat stress. Indigenous buildings should be used where possible because they usually are designed and sited to take advantage of prevailing breezes and often have thick walls which moderate daily temperature peaks. In the absence of refrigerated air conditioning, effective low-tech alternatives include evaporative cooling, natural or forced ventilation with outside air, and ceiling fans.

In addition to discomfort for patients and staff, high temperatures in medical facilities cause difficulties with housekeeping and equipment maintenance. It may be necessary to set up cooled storage areas for critical equipment and supplies to assure a reasonable shelf life. It is especially useful to have portable air conditioners and fans adaptable to AC and DC power sources. On arrival, medical personnel should establish communication with the meteorological office together with a system for advising base personnel regarding current and predicted temperatures and related weather conditions.

5.1 Air Transportable Clinic (ATC)

The USAF's ATC is designed to provide support to an operational squadron of 300-500 personnel in a bare-base setting. It is primarily intended for outpatient treatment and assumes that more serious cases can be transferred to a nearby hospital or immediately evacuated by air. The ATC should be sited to take advantage of any shade, prevailing breeze or other benefits offered by the surroundings.

Review of the TA shows that the clinic is not well suited to treatment of multiple heat casualties. Relevant equipment items in the TA include six oral thermometers, 12 L each of lactated Ringer's solution and normal saline, one urinary catheter set, a 150-L storage reservoir for heat-sterilized water, and 18 m of water hose with a nozzle. There is one ice bag, but no mechanism for chilling water or producing ice. Supplies for oral rehydration were recently added. The ATC's capacity for treating multiple heat casualties may be increased by adding supplies for oral rehydration as well as increased quantities of parenteral solutions, I V administration sets, and urinary catheter sets. In the absence of laboratory facilities, patients will have to be assessed for heat illness based upon clinical impressions, history, vital signs, mental status, appearance of skin and mucous membranes, as well as the occurrence of other heat casualties.

It is imperative that the clinic secure an abundant supply of cool water; if potable water is limited, a secondary source of non-potable water should be considered for special purposes such as evaporative cooling. Fans and portable air conditioners may be sought from engineering units, and the dining hall should be approached regarding availability of ice, ice chests and cold storage. In arid settings, porous water bags will cool their contents to well below ambient temperature.

5.2 Air Transportable Hospital (ATH)

The ATH is deployable in increments of 14, 25, or 50 beds. Its mission includes holding patients for evacuation or return to duty within 2-7 days. Normal staffing can accommodate 12 major surgeries and a peak of 20 admissions per day. It includes two beds for resuscitative surgery and post operative stabilization. Outpatient services can provide definitive management for up to 50 patients/day. The ATH can relocate within 24 h, but it requires external support services. Each deployable increment of the ATH includes air conditioners, circulating fans and limited refrigeration capacity.

The first increment includes intravenous fluids (Ringers lactate, normal saline, and dextrose in water) totaling over 200 cases at 12 L/case; the second and third increments each include additional IV fluids. The ATH does not have freezer storage for ice and is limited on the amount of cold storage for oral fluids. The TA has recently been revised to may include high-reading rectal thermistorrs and supplies for preparing oral electrolyte solutions.

When heat casualties are anticipated, it may be advisable to augment the normal TA with intravenous fluids, rectal thermometers, urethral catheters, and pharmaceuticals for seizure control. The ATH Commander needs to determine the availability of support services to meet extraordinary needs for refrigeration, cold storage, oral electrolyte supplementation and patient holding.

6. PROTECTING PATIENTS AND STAFF

Medical personnel working in hot climates are themselves subject to heat stress and illness. Health maintenance is particularly important in this group because their duties involve a combination of physical effort, skill and judgment affecting the welfare of their patients. All personnel must be made aware that heat stress affects performance, and that critical tasks should be routinely double-checked. Minor complaints or signs of impaired performance call for immediate corrective action, since problems in one person often indicate impending trouble for others. Special attention must be given to new arrivals who may be very tired and have not yet adjusted to hot conditions, as they are especially susceptible to heat exhaustion.

Supervisors must enforce adequate work-rest schedules and sleep discipline and should also attend to their own sleep needs. Sleep deprivation reduces heat tolerance, and heat stress interferes with sleep. A sleep session should last 4-6 hours if possible, but naps are better than no sleep at all. Those who work at night require special consideration because they may have trouble obtaining adequate sleep during the day; every effort must be made to provide cool, quiet sleeping quarters for these people.

6.1 Water and Food

A special effort is required to provide fluids frequently to both patients and staff members, and they must be encouraged to replace fluid loss on an hourly basis. Drinks should be readily available, cool and palatable. Plain or flavored water is preferable to beverages which are carbonated, contain caffeine or are heavily sugared. Meals should be used to encourage complete rehydration by providing large cups or glasses and large containers of water and flavored drinks.

Both patients and staff should be encouraged to eat all scheduled rations in order to replenish calories used for work and salt lost in sweat. Depressed appetite and weight loss are common occurrences under hot conditions, and eating at least one hot, sit-down meal per day is the most effective single means of ensuring adequate food intake. Personnel must not skip meals by substituting candy bars, snack foods, sugary drinks or electrolyte beverages (sometimes called "sports drinks"), items which lack important nutritional components. Those responsible for planning meals should monitor dining areas and patient trays to see which foods go uneaten.

Field rations generally contain ample salt in the food itself, but diners should add salt to conventionally prepared meals. Neither salt supplements nor electrolyte drinks are necessary if personnel are eating normally. Salt pills are not a recommended form of supplementation, as excess salt intake is a real hazard, leading to increased water requirements, high urine output, nausea, and greater susceptibility to heat illness.

6.2 Pitfalls

Any lapse of discipline in control of food and water quality in a hot climate can have immediate, disastrous consequences. Precautions must be taken to prevent the zoonotic and human transmission of endemic diseases including bacterial, viral and parasitic types. Use of indigenous supplies for food and water and/or local personnel to handle them are potential sources of enteric infection.

Commercial flavorings neutralize water disinfectants. Flavoring should therefore be added just before use, and flavored water must be stored under refrigeration and handled in the same manner as foodstuffs. Because ice is a possible source of contamination, drinks should be cooled indirectly rather than putting ice in the beverage.

Ice is a common medium for the spread of gastroenteritis, a problem which seems to require rediscovery on every major military deployment. Ice is readily contaminated in manufacturing and handling and cannot be disinfected. Only ice from approved sources with tightly controlled sanitary storage and handling should be used in drinks. If there is

any doubt about its purity, the ice should be used for indirect cooling of the fluids to be consumed.

7. ASSESSMENT OF INCOMING PATIENTS

Heat stress and dehydration should be expected in all patients arriving directly from the field, transferred after stays at low-echelon treatment facilities or transported over long distances in uncooled vehicles. Rectal temperature must be determined at once and may require use of special high-reading thermometers; vigorous cooling should be instituted for values over 40 °C (104 °F). Unconscious or disoriented patients (whether they are sweating or not) should be treated as heat stroke cases until this can be ruled out. All arriving patients should be evaluated for electrolyte disturbances to the extent possible with available facilities.

Conscious patients suffering from fluid deficit should be rehydrated using oral mixtures, reserving parenteral solutions for patients who cannot drink or retain liquids. In an emergency, large volumes of intravenous fluid can be given in a short period as long as cardiovascular and renal function are intact; in doubtful cases, hydration should be evaluated using central venous pressure.

Patients who have been stabilized but must be held under hot conditions require high water intake to compensate for sweat production (Fig. 1). Patient hydration should be monitored by all means available at the facility, including physical examination, morning body weight, blood studies, urine flow rate and urine specific gravity or color. Urine dip sticks can be very helpful in this regard.

Heat stress and dehydration may alter the presentation of casualties; conversely, certain battlefield conditions may increase the risk of heat stroke. For instance:

- Rectal temperature rises by 0.3 to 0.5 °C for each 1% loss of body weight.
- Hyperthermia alters the relationship between heart rate and blood loss
- Dehydration lowers the threshold for hemorrhage-induced shock
- Hypovolemic vasoconstriction diminishes ability to dissipate heat
- Spinal injury impairs sweating capacity
- Sunburn inhibits sweating in affected areas
- Anticholinergic agents suppress sweating

8. HEAT ILLNESS MANAGEMENT

Fig. 2 depicts a diagnostic tree for the heat illnesses. Although several different heat illnesses were distinguished in the older literature, the progression from heat strain to heat exhaustion and heat stroke is now viewed as a continuum. Nonspecific heat strain and dehydration can produce a variety of symptoms related to the central nervous system, including diminished alertness, irritability, agitation or disorientation. The combination of heat stress and combat may produce a confusing neuropsychological picture which includes elements of Combat Stress Reaction. Physical signs of heat stress may include peripheral edema, muscle cramps, or syncope. Recovery can be expected with a few hours of rehydration and rest in cool conditions.

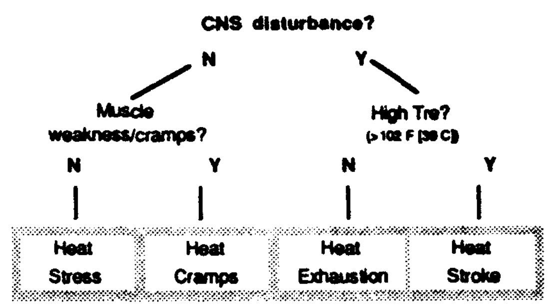

Fig. 2. Heat illness diagnostic tree.

Every effort should be made to obtain an accurate history with respect to conditions which may have precipitated heat illness and related problems:

- *Acute or chronic dehydration* due to inadequate fluid intake (shortage of potable water or conditions which inhibit drinking) or excessive fluid loss (vomiting, diarrhea, sweating or hemorrhage).
- *Electrolyte depletion* due to missed meals and/or plain water replacement for prolonged sweating.
- *Febrile illness* or recent immunization

- *Skin conditions* which interfere with sweating (heat rash, sunburn, chemical or thermal burns) or prevent evaporation (extensive dressings or other coverings)

- *Medications* affecting thermoregulation, for instance alcohol, amphetamines, anticholinergics, antidepressants, antihistamines, and phenothiazines, as well as exposure to toxins which cause tremors or muscle rigidity

- *Heat intolerance* as indicated by previous incidents of heat illness

8.1 Heat exhaustion

Signs and symptoms include various combinations of severe fatigue, irritability, headache, dizziness, nausea, vomiting, hyperventilation and syncope. Core temperature may be normal to moderately elevated. Due to its protean nature, heat exhaustion is generally a diagnosis of exclusion. Treatment consists of rest in a cool place (at least shade and good air movement) and vigorous oral rehydration. Intravenous fluids will be required if the patient cannot drink or retain oral fluids. Although full recovery may take 1-2 days, failure to respond promptly to treatment should raise the suspicion that the patient has suffered a mild heat stroke.

8.2 Heat stroke

This is a life-threatening condition characterized by elevated body temperature and mental confusion or loss of consciousness; the patient may or may not be sweating. Rectal temperature is usually in excess of 41 °C (106 °F) at the time of collapse, but may fall again before a reading can be obtained. Seizures are common. The differential diagnosis for heat stroke includes a variety of infectious diseases which cause fever and altered mental status, including encephalitis, meningitis, malaria, typhoid fever and typhus.

Rhabdomyolysis and renal failure are common in heat stroke incurred during physical exertion, and are associated with an elevated mortality rate; myoglobinuria may be detected as heme-positive urine dipsticks in the absence of red cells. Clotting disturbances are a late complication in severe cases. Patients with heat stroke suffer multisystem damage and retain increased vulnerability to heat stress for a period of months to years after their original injury, so that it is unwise to return them to duty under hot conditions (2).

The primary treatment for heat stroke is immediate reduction of internal temperature, as prognosis depends upon the amount and duration of hyperthermia. Various methods of rapid body cooling have been used over the years. Under field conditions the victim should be placed in the shade, stripped if possible, wetted down and fanned. At medical stations with refrigeration, the patient should be immersed in cool or chilled water to which ice is added when available. Ice packs or cold soaks may be substituted if immersion is not practical. Although some civilian clinicians advocate warm-water sprays with fanning as the optimal cooling technique, it does not provide the powerful cooling which is needed for exertional heat stroke (7). Intravenous solutions should be cooled before administration.

Because heat stroke patients need prolonged intensive care and supporting laboratory facilities, confirmed cases should be evacuated to major medical facilities as soon as they can be stabilized.

9. AIR EVACUATION

Heat stroke patients must be stabilized at rectal temperature < 38 °C and well hydrated with adequate urinary output. Seizures should be under control. Patients should have a functioning intravenous line and may require a urinary catheter, depending upon their level of consciousness. Complete medical records should accompany the patient, including a detailed account of fluid input and output and neurological findings. Conscious patients suffering from primary or secondary heat illness and dehydration should travel with prescribed quantities of oral rehydration mixtures or should have an open intravenous line for administration of fluid and electrolytes.

Aircraft parked in the sun are like ovens. Significant heat stress may occur among air crew members, maintenance personnel and passengers, especially in case of mechanical difficulties or cumulative delays. Heat casualties should not be loaded until just before takeoff unless cabin cooling systems are running on the ground. Night operations offer a cooler alternative for ground operations. Once airborne, the cabin environment is usually cool and sometimes cold.

10. SUMMARY

Recent US military operations in the Persian Gulf and in Somalia re-taught many of the lessons learned earlier concerning prevention and treatment of heat casualties. Furthermore, environmental heat stress is likely to assume growing importance in future military operations. Modern capacity for rapid airborne deployment makes it increasingly likely that troops trained in temperate climates or involved in winter maneuvers may suddenly find themselves working under hot desert or tropical conditions.

A flight surgeon who anticipates deployment to a hot climate or where NBC clothing may be required should review methods for preventing heat casualties and educate operational personnel in advance regarding appropriate precautions. New arrivals will be vulnerable to heat exhaustion and heat stroke due to the combined effects of sleep loss, circadian shift, dehydration, anxiety and unaccustomed physical exertion combined with environmental heat load.

11. ACKNOWLEDGEMENT

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Deployed Operations in the Heat: A Desert Shield Experience

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SUMMARY

Soon after Iraq invaded Kuwait in August 1990 the 58 Fighter Squadron was notified of the impending deployment to Saudi Arabia. Planning for the extreme heat was included from the beginning. When the squadron deployed to Saudi Arabia everyone was ready for the heat. Heavy water intake was emphasized at every level of command; this was to be the primary defense against the high temperatures. The maintenance crews rotated shifts at 0200 and 1400 local time so each shift was exposed about to the same amount of intense sun and heat. The only heat casualties were during a chemical defense training exercise. By the time the war began in January 1991 winter gear was used especially by the night shift personnel working in the cool desert night. Regular training exercises where high summer temperatures are encountered, taught the unit how and when to work along with the value of good hydration.

INTRODUCTION

My squadron, the 58 Fighter Squadron, deployed to Tabuk, Saudi Arabia in support of OPERATIONS DESERT SHIELD and DESERT STORM. As the flight surgeon I was responsible for the medical well being of this F-15 Eagle air superiority fighter unit. In this unique position I was assigned to the squadron and reported directly to the wing and squadron commanders. There were no senior medical corps officers in my chain of command. When not deployed my primary duty was medical care for the pilots and their families. I interacted as a functional member of the squadron by flying on a regular basis. Socially my closest friends were the pilots. While in Saudi Arabia I lived with the pilots.

When deployed my medical responsibility expanded to include care for the entire deployed unit and all the preventative medicine functions associated with the base. Caring for this slightly less healthy, larger population required a great deal of time and effort. Planning for base medical contingencies was also a formidable task especially when dealing with a host nation such as Saudi Arabia.

Medical assets at the deployed site included myself, four medical technicians, a military public health technician, and a bioenvironmental engineer technician. The base was over 1100 Km/600 miles from the nearest United States unit. The Saudi army had a hospital about 16 Km/10 miles away that we could use for emergencies only. This facility was well equipped and staffed mostly by westerners. Our access to this facility varied throughout the deployment.

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

HYDRATION

The pre-deployment planning included medical aspects, especially heat related issues, from the first meetings. Water was the priority issue. Water was contracted from local Saudi vendors in 1.5 liter plastic bottles. However it was a medical function to assure the water was safe. Bottled water was available in large quantities throughout the deployment. The source varied but our water was all produced in Saudi Arabia.

A secondary factor was the palatability issue with the water. We knew that the wing personnel would consume more water if it tasted better. Over 1800 Kg/4000 pounds of "Gatoraid" was purchased and was on one of the first loads of cargo. This proved to be one of the most valuable assets we had in Saudi Arabia. For the first month, when the temperatures were the highest, refrigeration was almost non-existent. Drinking hot/warm water was less than optimal. Any flavoring was better than nothing. The Gatoraid could be mixed to individual taste preference. Also the Gatoraid made the troops feel like the unit was going to extra measures to care for them, which was great for moral.

The debate on water versus electrolyte based fluids during a heavy load was not addressed at that time. We held the belief that the more of any fluid one took in was better than a lack of fluid. Some choose not to use Gatoraid or used other flavorings. That was the individuals' choice. All that mattered was that people were consuming large quantities of fluid. Since alcohol was not available, I was not concerned with the diuretic effects of alcohol or the substitution of valuable fluids for alcohol.

The second source of water I felt was also very important was intravenous fluid (IV). Each pilot flew with at least one liter of IV fluid along with the necessary tubing and catheters. The major method I chose to get a large quantity IV fluid to the theater was to have several cases of IV fluid everywhere pallets were being packed.. Nearly every pallet that was transported the first few weeks had at least one case of IV fluid and the accompanying hardware. We also packed more IV fluid on the Air Transportable Clinic (ATC) pallet than was called for in the standard table of allowances. This program worked and luckily we used very little of the IV fluid that made it to Saudi.

Oral hydration was emphasized at all times both before and during the deployment. The television news media actually helped by reporting the massive amount of water that everyone would require in the desert. Commanders and supervisors were diligent in making sure lots of water was consumed by everyone. The commander also waived the regulation about loose objects, specifically plastic water bottles, on the flight line. Water bottles would not normally have been allowed near the jets due to potential foreign object damage (FOD) of the engines.

WORK IN THE HEAT

The F-15 has a very good Environmental Control System (ECS). This keeps the cockpit cool even on the ground. As

soon as both engines start the canopy is closed and the pilots' thermal burden is essentially eliminated. The operations building was well airconditioned also. All the barracks rooms were airconditioned as well. Therefore the pilots were only subjected to extreme heat on the way to the jets and during pre-flight.

The ground personnel were subjected to the heat for their entire duty period. Given the number of deployed personnel and the required amount of work, a two shift rotation, twelve hours each, was established. The change over was at 0200 hours and 1400 hours. These hours were chosen so that each shift was exposed to the same amount of intense heat. By mid October the heat had moderated. The base gymnasium was the only source of off duty activity. The hours for United States use was changed so the work shift hours were also changed so everyone had equal access to the gymnasium.

Individual supervisors were tasked with rotating personnel during the heat of the day. The pace of the work depended a great deal on the mission demands. Luckily early in the deployment the air activity was rather modest compared to when the war began in January, 1991. The maintenance personnel found keeping the jets flying during a summer Red Flag deployment at Nellis Air Force Base, Nevada excellent training for operations in Saudi Arabia. There the temperature is often over 43 C./110 F. When any member felt too hot they were allowed to rest. We had no heat casualties with this system.

Shade was a highly sought after commodity in the desert. Whether it be a building, aircraft shelter, or simply just being under the jet itself. Anything left in the sun rapidly got too hot to touch without gloves. The exposed parts of the jets got too hot to work on. When the pilots climbed in they found the cockpit area too hot if the canopy had not been left open. Sun shelters and aircraft shelters were the primary places any work was done on top of the jets during the day. Issuing gloves that provided adequate dexterity for the maintenance troops was important. The best gloves proved to be the pilot flight gloves. They are leather palmed for protection and nomex backed for coolness.

The use of the wide brimmed, "floppy", hat also helped decrease the sun exposure. Not only did it help keep the head cooler but it prevented sun from blistering the tops of the ears and the nose. Also their skin was already conditioned by the sun. Coming from a hot, sunny climate like the coast of Florida was a real benefit. The clinic and each units supply area issued sunscreen and lip balm. We had very few cases of sunburn. Sunglasses were also worn by most personnel. These were good quality glasses personally procured for the Florida sun. They also helped keep some of the blowing dust and dirt out of the eyes. Everyone was issued goggles for the sand but few wore them.

COLD

The deployment continued into the winter months. By the time the war began in January, 1991 the temperatures on the

desert were cold especially at night. No one brought cold weather gear in August so thermal underwear, coats, and gloves were issued to the troops. Also the mail system was working well be that time and personnel had cold weather clothes sent from home. It was not unusual for wind chill temperatures to be below -15 C./5 F. at night. The war was fought around the clock. Again supervisors were responsible for insuring everyone had adequate warm clothes for the long nights. There were no cases of frost bite seen at our base.

Once again the pilots were not subjected to the cold for long periods of time. They were, however, concerned about the possibility of ejecting during the cold nights. During ejection all you take with you is what you have on. No one wanted to be evading in Iraq and become a casualty of the cold first. All wore thermal underwear beneath their flight suits in case this happened.

CHEMICAL DEFENSE TRAINING

The only heat casualties came while the unit exercised in a chemical defense scenario. Everyone deployed had exercised with the chemical warfare defense ensemble before deployment. They were all familiar with the heat load imposed while wearing the suit. Unfortunately there were no training suits available for exercise scenarios at our deployed site. Due to the limited shelf life of a suit once it has been opened, use of the suits in an exercise was not possible. As a substitute rubber rain suits were worn for an exercise. As little as the chemical suits breath and as much as they build up heat the rain suits were much worse. There were three heat victims who were brought to the clinic for care. All three had rectal temperatures over 40 C./104 F. They were aggressively cooled with water and fans. Each received three liters of IV fluid. All three recovered uneventfully. From that point on we exercised with the mask only and did not simulate the chemical suit with a rain suit. Personally I had never lost so much fluid and become so hot as during that particular exercise. The rain suits did not breath at all. My flight suit literally dripped at the creases when I came out of the suit to treat the casualties. In retrospect this scenario may seem dumb or shortsighted, but at the time training realism was a priority. We wanted the unit to be prepared in case we were attacked with any weapon.

CONCLUSION

There were many factors which made this deployment successful. First among them was the excellent command involvement and decisions throughout the planning, deployment, and finally operating in the adverse environment. If it was possible to do it the correct way the unit did it that way. The command understood and took the responsibility for aggressive hydration. They also used the personnel in the smartest manner possible to minimize the heat exposure to each member. Deploying from a hot climate where everyone was already acclimated to the sun and heat was very beneficial also. Using already acclimatized troops should be a recommendation for any future deployment. The training our unit received on a regular basis before the deployment was

key. Even though the environmental conditions were more severe in Saudi Arabia the guiding principles learned in a hot environment could be applied there also. Without good fortune, the foresight of our commanders, and excellent training the opportunity existed for severe problems due to the heat. Luckily we did conquer this environmental obstacle.

WORK CONDITIONS ASSESSMENT IN PILOTS AND GROUND PERSONNEL UNDER HIGH WEATHER TEMPERATURES

by

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INTRODUCTION.-

Human and animals often exhibit a remarkable ability to adapt to harsh or rapidly changing environmental conditions. One obvious means of adaptation is to move to where the environmental stress are less severe. The body also has many physiological response for adaptation. There is an ample literature on adaptative mechanisms and processes (10). When a person becomes acclimatized the hypothalamus an other body control organs and systems settle into cooperative equilibrium, with certain chemical or hormonal levels that are appropriate for that particular season (11).

An unacclimatized personnel is unfit but after successive daily exposures to heat becomes more able to work and they feels the heat less. Heat regulation is improved, at least in part, by the induction of sweating at a lower internal body temperature (10). Sweating appears to be the main thermoregulatory mechanism operating in hot environments. Sweat is hypotonic to plasma, and exercise depletes both intracellular and extracellular fluid volumes.

The summer climate in the south of Spain is characterized by high ambient temperatures and, in our area, there is a high percentage of humidity usually. These environmental conditions, provoke a high heat stress either aircraft crews and ground personnel. Even though all personnel assigned to Badajoz Air Base are acclimatized to these harsh conditions, the fact of performing an air exercise, which require to maintain aircrafts in a condition of readiness for immediate takeoff, and a permanent ground standby alert situation, may significantly add to the total heat stress load.

The present study, describes how simple dietary rules, can prevent the hurtful consequences following to involuntary dehydratation provoked by sweating.

MATERIAL AND METHODS.-

This study has been performed on Badajoz Air Base in August 92, along two weeks, during "Encina 92" air exercise. Badajoz Air Base is

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located in the southwest of Spain, near to Portugal border.

116 subjects, military personnel, belonging from Spanish Air Force, assigned to Badajoz Air Base were studied. All subjects were acclimatized to the habitual environmental temperatures. The prolongation of the work time and the changes in the usual schedule were the only differences from the habitual work conditions. The Table 1 shows the main data about all groups.

Anthropometric Data

Groups	n	Age	Height *	Weight **	BMI
A = Controlled P.	30	27,5±2,46	175,5±5,12	77,12±5,81	25,0±0,8
B = UnControlled P.	25	27,4±2,74	175,9±5,21	78,08±7,32	25,2±1,3
C = Controlled M.	27	30,0±4,66	174,7±4,36	77,31±5,77	25,3±0,8
D = UnControlled M.	34	30,8±4,66	175,0±0,04	77,25±5,53	25,2±1,2

P = Pilots * = cm All data: Mean±SD

M = Mechanics ** = Kg

Table 1

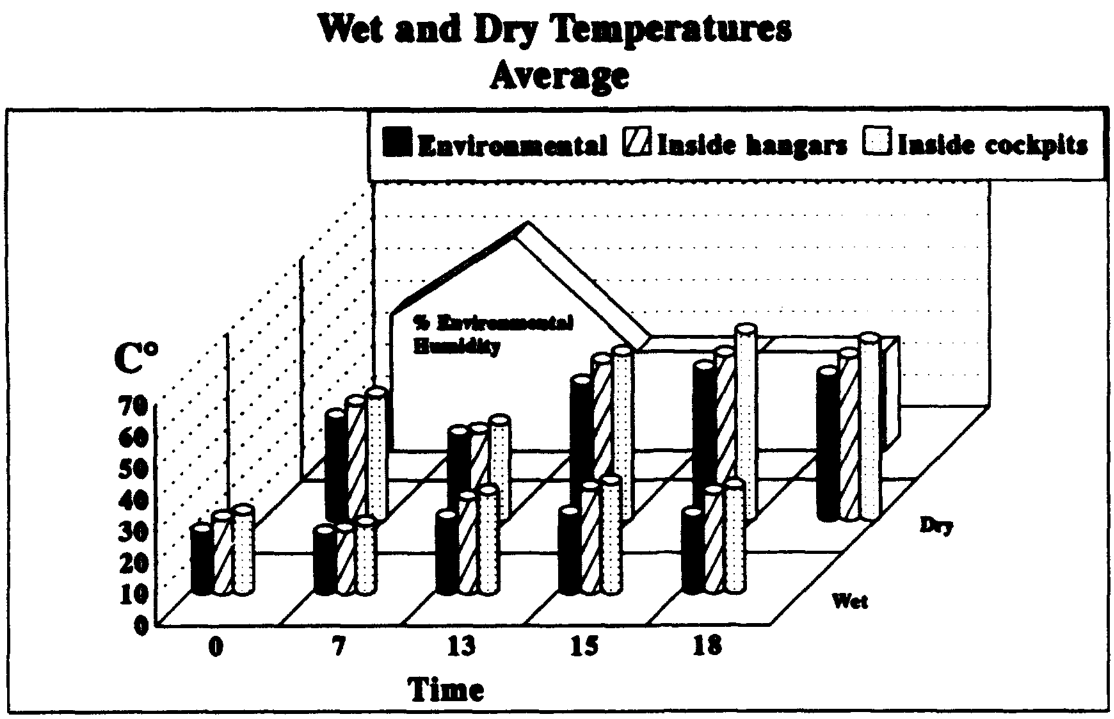
The Southwest of Spain is characterized by very hot weather summers. Wet and dry temperatures were obtained by mercury conventional thermometers PHIES (See Figure 1). The wet temperature, was obtained by a thermometer wrap up in a thin cloth, moisten with distilled water. All thermometers are placed inside an special container over the grass in shadow area near to control tower. Wet Bulb Globe Temperature (WBGT) (Figure 4) and Fighter Index Thermal Stress (FITS) (Table 2), were used as index of thermal stress, and WBGT was calculated from the standard formula: WBGT = 0.7*Wet temperature + 0.3*Dry temperature (3).

FIGHTER INDEX OF THERMAL STRESS (FITS)

C° \ % HUMIDITY	20	30	40	45	50	55	60	70	80
24,5			70	70	71	72	72	73	74
26,1	70	71	72	73	73	74	74	76	77
27,2	71	72	73	74	75	75	76	77	78
28,3	72	73	75	75	76	77	78	79	80
30,0	73	75	77	78	78	79	80	81	83
30,6	74	76	77	78	79	80	81	82	84
31,1	74	76	78	79	80	81	81	83	85
31,7	75	77	79	80	80	81	82	84	86
32,8	76	78	80	81	82	83	84	86	87
33,3	77	79	81	82	83	84	84	86	88
34,4	78	80	82	83	84	85	86	88	90
35,0	79	81	83	84	86	86	87	89	92
35,6	79	81	84	84	86	87	88	90	94
36,7	80	82	85	86	87	88	89	93	98
37,8	82	84	86	87	88	90	91	97	104
40,6	84	87	90	91	92	84	96	103	108
41,0	86	88	92	93	94	96	101	107	110

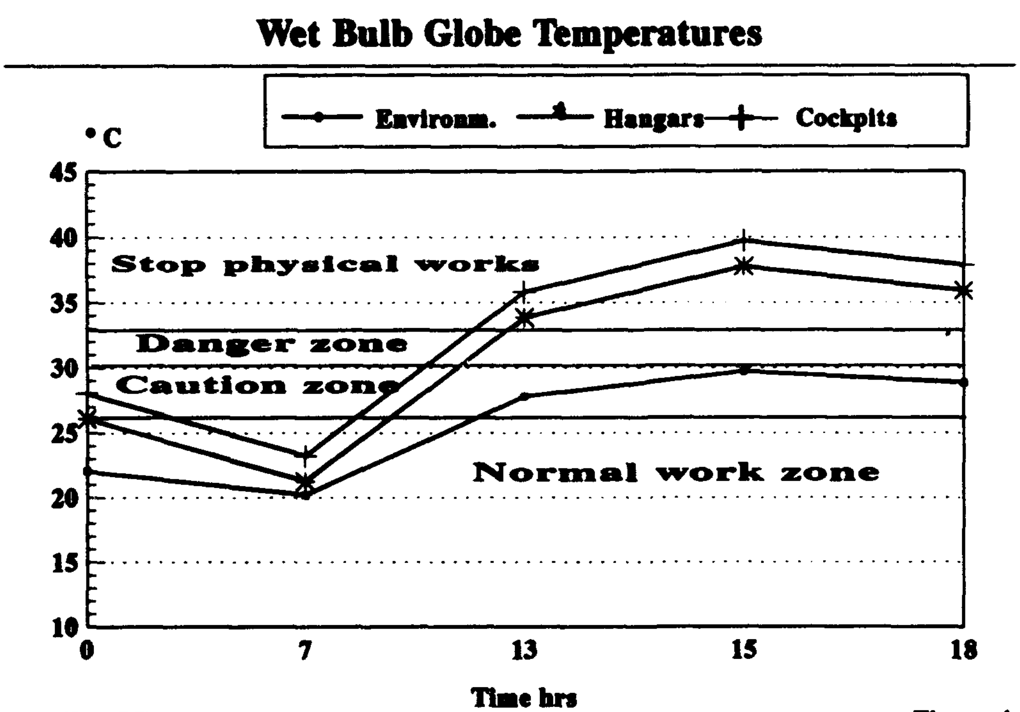
ALERT DANGER EMERGENCY

TABLE 2



JGA & JMV

Figure 1



JGA & JMV

Figure 4

The table 3 summarize the standard military clothes in Spanish Air Force on summer time for both pilots and mechanics.

Work Uniforms SAF

Pilots	Mechanics
Flight suit	T-Shirt (cotton)
Anti-G suit	Trousers (cotton)
Flight boots	Boots
Helmet	Cap
Gloves	

Table 3

The figures 2 and 3 show the timetable of pilots and mechanics activities and environmental conditions. The most part of the physical activities for all groups studied, were aerobic, even though the pilots, during the air combats, were under anaerobic conditions because anti G straining maneuvers.

Pilots's work scheduled

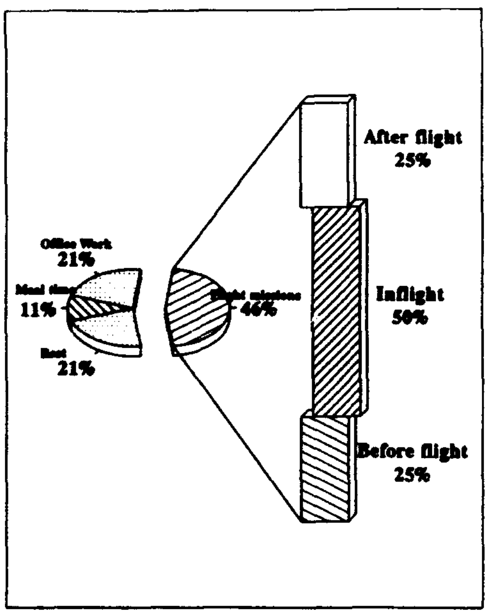


Figure 2

Mechanics' work scheduled

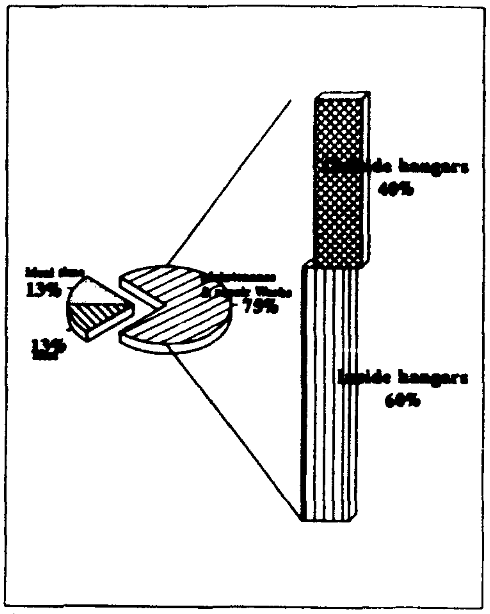


Figure 3

The programmed dietary intake was a "typical mediterranean diet" characterized by following ratio: 55 - 60 % carbohydrates, 25 % lipids and 15 - 20 % proteins. The caloric amount was 3.000 Kcal daily, split into three main and two "minor" intakes (4). See table 4.

Programmed Diet

- Daily Caloric amount 3000 Kcal
- Ratio: 55-60 % CH.; 25 % Lip.; 15-20 % Prot.
- Split in: 3 main & 2 "minor" intakes
- At 14 O'clock: "Gazpacho" (500 ml)

Table 4

Likewise all controlled personnel must drink water (pilots drunk 1500 ml for three hours before flight, and mechanics drunk 3000 ml for the work time).
In order to measure the water reposition in uncontrolled

subjects, they must note the amount of liquid intakes every time they drunk. In addition, in the main meal, at 14 o'clock, all controlled subjects must drink half a litre of "gazpacho", a typical spanish liquid summer-food, rich in carbohydrates, vitamins and mineral salts, with the composition listed in table 5.

Gazpacho

- **Tomatoes and bread**
- **Green pepper**
- **Cucumber**
- **Olive oil, salt, garlic, vinegar and water**
- **Vitamins: A, B, C, E, H, PP.**
  Acids: Folic, Oxalic, Malic
- **Ions: Na, Ca, Fe, Mg, Mn, K, P, S, Cl and Cu.**

Table 5

Fluid Balance and Fluid Deficit were calculated as follow:

FB (ml)=H_2O intake (ml) - Sweat rate (g)

FD (%)=[Sweat rate(g)-H_2O intake (ml)]/[Sweat rate (g)*100] (1).

At the end of the exercise, all studied groups were submitted to an inquiry asking about the following topics: see table 6.

INQUIRY

Topics	Punctuation key
Tiredness	1 = Nothing
Irritability	2 = Little
Mental ability	3 = Normal
Libido	4 = Large
Thirst feeling	5 = Very Large
Post Sleep well-being	

Table 6

In this study were measured the parameters shown in table 7.

Objective parameters meassured

Pilots & Mechanics			Pilots
Start Study	End Study	Daily	Pre & Post Flight
Body Weight & Height	Body Weight	Water Intake	Body Weight

Table 7

Statistical analysis was performed using the One-Way MANOVA test, the Man-Whitney, Student's T and Cochram test.

RESULTS.-

Figure 5 shows fluid changes in pilots. In this parameter it has been together considered all fluid loss: sweat, urine and respiratory loss. We don't find any *significative* difference between Group A and B in the weight loss.

Fluid changes
Pilots

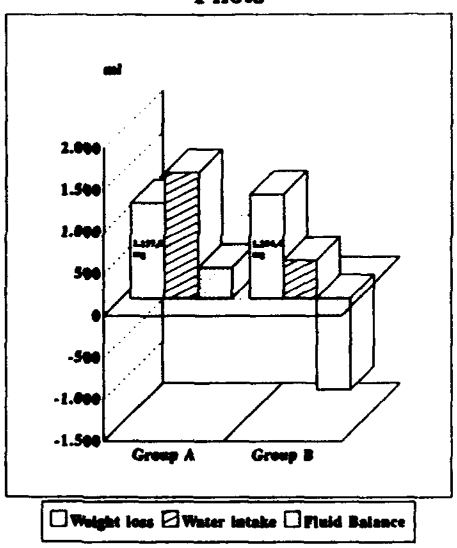


Figure 5

On the other hand, a significative statistically ($p<0.01$) difference between Group A and B in the fluid balance has been found.

Fluid changes evolution, in mechanics (see figure 6), was similar that in pilots. No significative differences were found in loss of weight. But a significative statistically ($p<0.01$) difference between groups C and D was obtained in the fluid balance.

Fluid changes
Mechanics

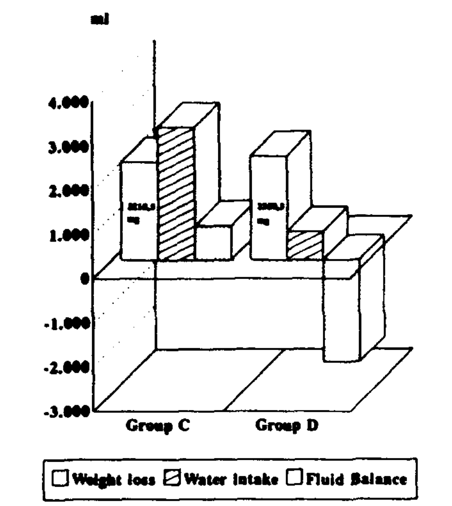


Figure 6

The Controlled Groups (A and C) and Uncontrolled Groups (B and D), with a similar loss of body weight, shown a remarkable difference in Fluid Balance.

Figure 7 shows the fluid deficit observed in uncontrolled subjects, Groups B and D, versus the positive fluid balance observed in controlled subjects, Groups A and C.

Fluid Deficit

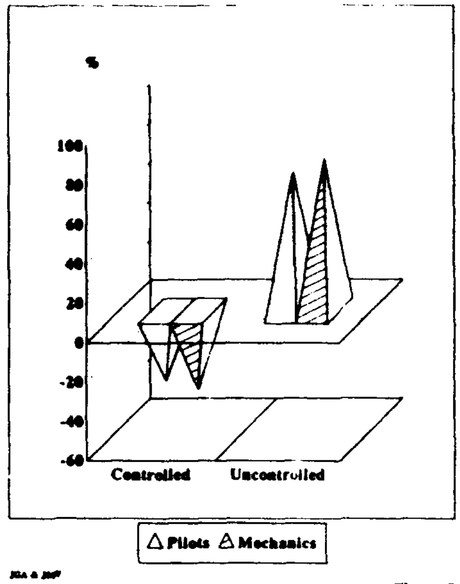


Figure 7

Figure 8 shows the results obtained from the inquiry answered by the pilots. A significative statistically differences between groups A and B were found in Tiredness ($p<0.01$), Irritability ($p<0.01$), Thirst ($p<0.01$) and Post-Sleep well-being ($p<0.01$). No significative differences were found in the remain questions.

Inquiry
Pilots

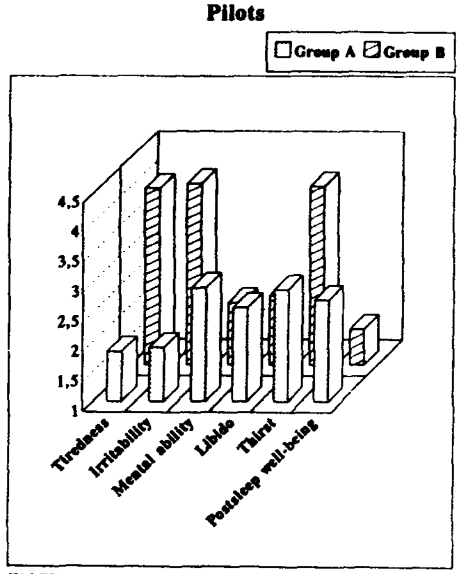


Figure 8

A significative statistically ($p<0.01$) difference between Groups C and D, in the thirst was the only remarkable finding. Controlled mechanics (Group C) shown less tiredness and irritability than uncontrolled mechanics (Group D), but this data did not have statistical signification. Figure 9.

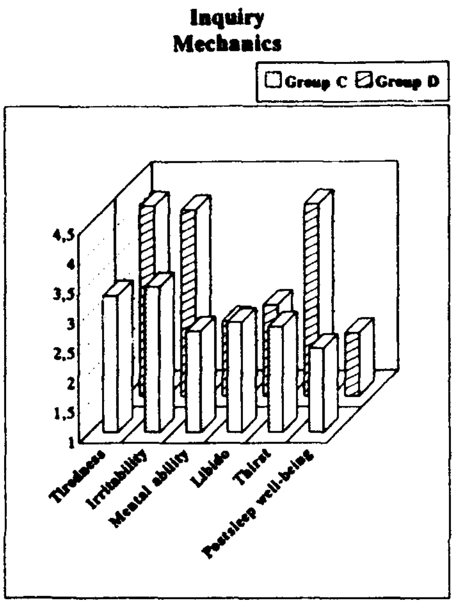


Figure 9

DISCUSSION.-

Before starting with data analysis, we think doing the next explanation is useful: All ground personnel were submitted to the same heat stress level, because the mechanics activities are similar along the time work. For this reason, the mechanics data relative to weight loss and fluid intake, were expressed as the mean value of the all measures take along the working day. On the other hand, the data about the pilots were collected at the start and the end of the flight missions. This fact point out that the pilots could were submitted to different heat stress level motivated by the different take off time. But, along of the two weeks of air exercise, they change the take off time every day. Since, they were submitted to the same heat stress level, we have considered the mean value of data as the ground personnel.

Subjects with fluid intake guided only by thirst (groups B and D), shown a negative fluid balance versus subjects with compulsory fluid intake that maintained a positive fluid balance. The involuntary dehydratation - fluid deficit - observed in these uncontrolled Groups, go on unadvised for them. In this way, results show the fluid deficit observed in uncontrolled subjects, Groups B and D, versus the positive fluid balance observed in controlled subjects, Groups A and C. This Fluid Deficit observed in Uncontrolled Groups, is caused by the delay of drinking sufficient fluid to compensate for fluid loss when humans are subjected to stressful conditions, usually exercises and heat exposure, as in the present study (6).

For this reason, making methodical hydratation guidelines to subjects working under hot and stressful environment is fundamental to avoid involuntary dehydratation and its following consequences.

Sweat is hypotonic to plasma, and exercise - particulary in a hot environment - depletes both, intracellular and extracellular fluid volumes (9). The result is usually an increase in plasma sodium and osmotic concentrations, which in turn could stimulate thirst

and drink. Frequently, minimal changes in osmolality during exercise in stress environment would not have been of sufficient magnitude to induce significant drinking. But, the central nervous system is very sensitive to internal medium variations, changes in fluid and electrolyte concentration specially (5). Even thought this changes do not have effect over the main brain functions and the subjects do not stopping normal daily activities, this fluid changes might have repercussion on tiredness, irritability, post sleep well-being etc..which could be cause of performances decrease (2, 7, 8 and 12) in both, pilots and ground personnel, affecting to flight safety. Although the level of heat stress wich results in decreased pilot performance and an increased risk of both pilot error and accident is not known, the decline in efficiency of mental functions and physical work output as a result of increased thermal stress is well established (7). In this study, subjects with a positive fluid balance shown better physical and psychological condition than subjects with fluid deficit.

People have developed traditional cook in order to adapt the different food to seasonal environmental conditions. In this sense, in our country, the "Gazpacho" is an energetic liquid meal, rich in electrolytes and vitamins, very adequate to drink in the summertime in warm regions since under hot weather temperatures, people can be remain inappetent and they prefer drink to eat. In this way, "gazpacho" is a cool drink nutritive, refreshing and it have a very good taste.

In conclusion, since getting a total climatized ambient in all work areas, it is impossible, a controlled and compulsory fluid intake in personnel submitted to harsh ambiental conditions, that provoke high heat stress load, it can prevent negative effects of sweating increase as adaptative mechanism to hot environment. This controlled and compulsory hydratation, cheap and easy to do, could prevent performances deficit, either pilots and mechanics, contributing to maintain a better level of flight safety.

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THERMAL STRAIN GENERATED BY AN ENHANCED ANTI-G PROTECTION SYSTEM IN A HOT CLIMATE

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SUMMARY

A flight trial was conducted at RAF Akrotiri to assess the level of thermal strain associated with, and the G protection provided by, the prototype European Fighter Aircraft (EFA) Interim aircrew equipment assembly (AEA) in a warm climate. Six subjects flew a standardized sortie four times in the RAF IAM Hawk aircraft: two while wearing the EFA AEA and two wearing standard Hawk Summer AEA. The sortie profile included simulated air combat and four high G turns. Cockpit temperatures, rectal and skin temperatures, heart rate and sweat rate were recorded. Subjective thermal comfort, fatigue and G tolerance were also assessed. Skin temperatures at the chest, back and upper thigh sites and mean skin temperatures were greater in flight and sweat rate was increased when the EFA AEA was worn. However, rectal temperature and heart rate did not differ significantly when the EFA AEA was worn, indicating that homeostasis was maintained by thermoregulatory mechanisms. Superior G protection was provided by the EFA AEA. Taken as a whole, these findings suggest that wearing the EFA AEA in a warm climate is associated with an increased but not unacceptable level of thermal stress while offering greater G protection. These results may not generalize to conditions where ambient temperatures are higher or where more insulative protective clothing is required.

1. INTRODUCTION

The European Fighter Aircraft (EFA) is an agile combat aircraft capable of sustaining levels of $+G_z$ acceleration higher than can be passively tolerated by aircrew using current methods of protection. To reduce the effort required to tolerate high G, a G protection system has been developed which employs increased coverage anti-G trousers and positive pressure breathing with chest counter-pressure. Centrifuge studies have shown that these garments allow $+9\ G_z$ to be tolerated with little more than moderate muscle tensing and reduced levels of fatigue. These findings were confirmed in a flight trial of the enhanced G protection system using the RAF IAM Hawk aircraft.(1)

This enhanced G protection system, embodied in the EFA interim AEA, involves covering an extensive area of the body with an impermeable layer and it has been suggested that this may produce an unacceptable level of thermal stress compared with existing anti-G AEA. Centrifuge studies have shown that thermal stress is associated with a reduction in passive G tolerance.(2,3) If significant thermal stress is produced by wearing the EFA interim AEA, this may compromise the level of G protection provided by the assembly and affect aircrew performance and flight safety. These effects may be exacerbated when operating in a hot environment.

Standard anti-G AEA, which has much reduced coverage compared with the EFA AEA, provides a lower level of insulation and a lesser impedance to sweat evaporation, particularly over the torso. However, exposure to the levels of +Gz likely to be experienced in the EFA would require aircrew to perform a maximum anti-G straining manoeuvre (AGSM). This manoeuvre generates significant levels of metabolic heat which if not dissipated to the environment may produce thermal strain thereby reducing G tolerance.

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The objective of this trial was to compare the level of subjective and objective thermal strain imposed by the prototype EFA interim AEA with that produced by standard AEA in a hot climate and to assess any associated change in G protection.

2. METHOD

Subjects. Six pilots, aged from 27 to 48 years, volunteered to participate in the flight trial. Subjects' total flying hours ranged from 1500 to 6500 with a mean of 1947. Hawk hours ranged from 100 to 800 with a mean of 395.

Design. Each subject flew 4 sorties, 2 wearing the standard Hawk summer AEA and 2 wearing the EFA interim AEA. The pressure breathing schedule provided by the modified 517 regulator fitted to the Hawk aircraft during this trial provided pressure breathing from +1.0 G_z with pressure increasing by 10mm $Hg.G_z^{-1}$. The anti-G trousers were inflated by the standard Hawk anti-G valve fitted with a pressure relief valve which operated at 12.5 psi. The sorties were flown at 3 different times of day; 4 of the pilots were tested at 0900h and 1300h, while the remaining 2 flew only at 1100h. Each subject flew only one sortie per day. This unbalanced design was adopted to provide a completely balanced element - the 4 pilots tested at 2 times of day - which would be relatively easy to complete in the face of equipment failure or other trial difficulties. The additional data from the 1100 sorties could be added independently. The allocation of clothing assemblies to sorties ensured that the comparison between different AEAs was uncontaminated by time of day or subject effects.

Sortie Profile. The sorties were flown in the RAF IAM Hawk XX327 and consisted of a structured, pre-arranged flight profile which was designed primarily to simulate the anticipated workload and G environment of air combat in EFA but which also

1. Wearing full AEA excepting helmet, leave AC ops accommodation, and walk to Flt Line Control.

2. Walk from Flt Line Control to aircraft.

3. Complete aircraft initial and external checks.

4. Strap in, pre-start checks, close canopy, start engine and post start checks.

5. Taxy to runway holding point.

6. Take off and initial climb.

7. Transit to 'High Gz' datum position to south of airfield.

8. Execute wind up turn to +5.5 Gz (1st High G turn).

9. Climb to FL 250 and maintain for 10 mins.

10. Re-position to 'High Gz' datum position and execute wind up turn to +6.5 Gz (2nd High G turn).

11. Climb and commence directed simulated ACM for 10 minutes.

12. Re-position to 'High Gz' datum position and execute wind up turn to +7.5 Gz (3rd High G turn).

13. Enter Akrotiri circuit pattern for instrument and visual approaches (approximately 5 minutes).

14. Re-position to 'High Gz' datum position and execute wind up turn to +8.5 Gz (4th High G turn).

15. Recover and land at take off +45 minutes

16. Post-landing checks

17. Taxy in, close down, canopy open and climb out.

18. Return to ops accommodation via flt line.

19. Debriefs etc.

TABLE 1

EXPERIMENTAL FLIGHT PROFILE

included additional elements to manipulate thermal stress and to assess G protection (Table 1). A 10 minute period at 25,000 ft (FL250) was included in the flight profile to simulate the cooling that might be obtained during a high level transit. This had the additional advantage of separating the thermal stress of the pre-flight period from that associated with subsequent elements of the profile. Three visual circuits were included to simulate the thermal stress of low speed, reduced power flight.

Environmental Measures. Meteorological data consisting of dry bulb (T_{db}), wet bulb (T_{wb}), and wet bulb globe temperatures (T_{wbgt}), surface wind speed and direction, cloud cover, and other significant weather, were collected for the take-off times of each sortie. T_{db} and relative humidity (%RH) were measured in the room in which the subjects were instrumented and dressed. Throughout each sortie, cockpit T_{db}, T_{wb} and miniature black globe temperatures (T_g) were measured using a sensor cluster mounted on the left-hand side of the front ejection seat and were recorded by an airborne thermal data recorder (ATDR).

+Gz acceleration was measured using an accelerometer (530 ADA/32, Smiths Industries; +/-12G) mounted on the right console of the rear cockpit. Output from the accelerometer was passed to a signal conditioning card, converted to a digital signal and was recorded digitally using a video character inserter card to produce an image of the numerical value of the level of G_z on the video tape recording from the camera in the front cockpit.

Physiological Measures. The physiological measures were deep body temperature using a thermistor (YSI 700 series) inserted 10 cm beyond the anal margin, skin temperature using thermistors (YSI 700 series) at the 8 sites detailed in Table 2, heart rate using ECG electrodes, and sweat rate

forearm
biceps *
chest *
abdomen
upper back
lower back
thigh *
calf *

Skin Thermistor Sites
(* Sites for Ramanathan mean)

TABLE 2

by nude weighing. Temperature and heart rate data were recorded at one minute intervals on a man-mounted, airborne thermal data recorder (ATDR) designed and built at the RAF IAM. The thermistor and ECG electrode leads and the lead for the cockpit environmental cluster sensors were connected to the ATDR by a series of multi-pin connectors which were stowed under the flying coverall in a fabric pouch held on a waist belt. Once the subject was fully dressed, the ATDR was inserted in the left thigh pocket of the anti-G trousers and the instrumentation harness lead was connected.

Subjective Measures. Subjective thermal comfort, fatigue, effort necessitated by anti-G straining manoeuvres, and visual loss under G were assessed using 5 point rating scales developed for this trial. Following each sortie, subjects participated in a structured interview to record overall thermal comfort, subjective G protection, fatigue, incidence of arm pain and other physical symptoms and to assess the comparative effectiveness of the Hawk standard and EFA Interim AEAs.

3. PROCEDURE

Prior to the trial, subjects attended RAF IAM for AEA fitting and centrifuge-based high $+G_z$ training up to $+7.4\ G_z$ as proposed for EFA aircrew. Before the trial, each subject completed a 7 day acclimatization period at RAF

Akrotiri.

On the day of testing, subjects reported two hours before scheduled take-off time for instrumentation in an air-conditioned room (T_{db} 21°C to 25°C; RH 40% to 50%). Baseline thermal comfort and fatigue levels were recorded. Following insertion of the rectal thermistor, subjects were weighed nude and then instrumented with the ECG electrodes and the skin thermistors at the sites detailed in Table 2. Subjects were re-weighed following donning of the previously weighed AEA. ATDR logging was initiated and further thermal comfort and fatigue ratings were recorded. Subjects remained in air-conditioned accommodation until they walked the 100 metre distance to the aircraft to conduct preflight checks. On completion of external checks the subject donned his helmet, chest counter-pressure garment (CCGP) and lifejacket, fatigue and thermal comfort were recorded, the subject strapped in, and the cockpit sensor cluster was connected to the ATDR. A check of ATDR function was made at this stage. The aircraft cockpit was covered by a canvas shade which was rolled away prior to canopy closure.

The sortie profile was directed from the rear seat by a RAF IAM pilot who acted as aircraft captain and who recorded subjective thermal comfort, fatigue, AGSM effort and visual loss under G. This direction ensured that each flight profile was identical in content and duration (Table 1). The 4 $+G_z$ turns and the simulated ACM were performed over the sea at altitudes of 2,000 to 8,000 ft. Subjects were instructed to perform the AGSM as normal when wearing standard AEA but when wearing the EFA AEA to strain only if visual loss occurred. Air combat was simulated by requiring the subject to detect a threatening aircraft, the position of which was indicated by the aircraft captain's raised hand. An open hand indicated a 'threat' within lethal firing range requiring a maximum $+G_z$ turn for survival. A closed fist represented a threat outside firing range which required a defensive manoeuvre whilst maintaining visual contact. Each threat was presented once per minute in random positions behind the pilot and involved 15 seconds within lethal firing range and 15 seconds out of firing range. This required the subject to make continuous head and torso movements to keep visual contact with the threat whilst exposed to a moderate to high $+G_z$ environment. This profile was designed to simulate the metabolic demands of air combat whilst standardizing the workload in a reproducible way.

Throughout the flight the cabin conditioning system control remained at the mid-point position. This provided a moderate degree of cooling without risk of the system ceasing to function normally due to freezing.

On completion of the sortie, the cockpit environmental cluster was disconnected from the man-mounted ATDR, and the subject returned to the instrumentation room. He was weighed clothed, assisted in doffing flying clothing and instrumentation, and was then re-weighed nude prior to removing the rectal thermistor. The short, structured interview followed.

Data Analysis. Measures of physiological and environmental variables were gathered at one minute intervals throughout the flight. Subjective assessments were collected at 13 key points; to simplify interpretation the analysis of the physiological measures was confined to the same time points. All measures were initially compared using analysis of variance (ANOVA). Four factors were identified: occasion within the sortie - 13 levels; time of day - 3 levels; AEA - 2 levels; and subject, which was treated as a random effect. In addition, the ANOVA was used to check for effects of sortie sequence on all the variables in order to detect any systematic change in conditions or effects of acclimatization. Comparisons between time of day are partially between and

partially within subject. All remaining comparisons are within subjects, as are time of day interactions with the other factors. The major part of the analysis was directed towards differences between the 2 AEAs and the more complex comparisons between times of day have not been investigated in detail. For significant AEA interactions the means for the 2 AEAs were compared using Dunn's method for each of the levels of the other factors. The subjective measures were investigated in more detail using analysis of covariance to seek possible explanatory relationships with physiological or environmental measures. The digitally recorded $+G_z$ data were analysed by fitting an upward linear trend to represent rate of G onset, a period of constant G representing the turn, and a declining linear trend to represent recovery from the turn. This provided 3 key parameters: rate of onset of G, G level during the plateau, and duration of the plateau. These were then investigated using analysis of variance with the same factors as the main body of the measures.

4. RESULTS

All sorties were flown in accordance with the planned profile, and at the planned times of day. Timings and durations were accurate to less that +/- 2 minutes. One sortie (Day 1, 1300 TO) was repeated due to failure of the ATDR. During another sortie the +7.5 G_z turn was abandoned for flight safety reasons.

Analysis of the results showed that there was no systematic change in the environmental conditions nor did the physiological and subjective measures show any systematic change with time throughout the trial period.

Ground Environment. Four measures of external conditions (T_{db}, T_{wb}, T_{wbgt} and %RH) were analysed for differences between times of day and between clothing conditions. A simple model taking account of the 2 effects and their interactions was fitted to the

Time (h)	Tdb Std	Tdb EFA	Twb Std	Twb EFA
0900	28.4	28.6	22.8	22.8
1100	30.0	31.8	24.1	23.2
1300	30.4	31.8	24.1	22.8

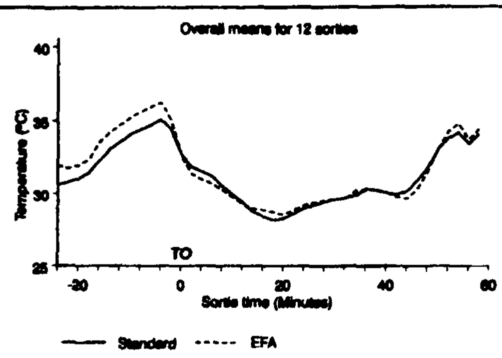
Time (h)	Twbgt Std	Twbgt EFA	%RH Std	%RH EFA
0900	27.2	26.5	62.5	62.5
1100	28.4	28.0	61.0	50.5
1300	28.1	27.8	60.5	47.5

Mean Meteorological Conditions

TABLE 3

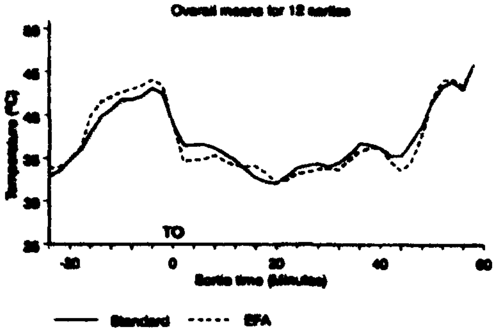
observations to test for systematic bias. No differences were found (Table 3).

Cockpit Environment. Cockpit conditions varied significantly throughout the sortie and T_{db}, T_g and RH were also influenced by time of day. There was no systematic bias between the 2 different AEAs. Thermal stress showed a consistent pattern throughout all the sorties with high T_{db} during taxi and line up for take-off (35°C-40°C) at 1300h and slightly lower values earlier in the day (Figure 1). T_{db} fell to between 25°C and 30°C during the 10 minutes at FL250 and then climbed during the rest of the sortie to values between 30°C and 35°C by the time the aircraft had landed and was taxying back to the dispersal.



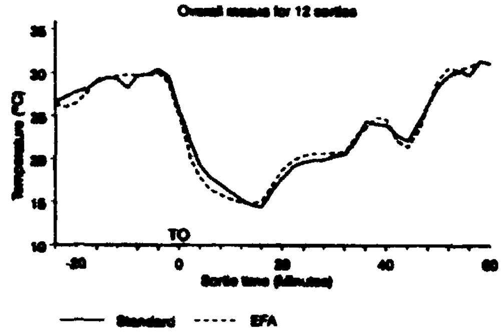
Cockpit Dry Bulb Temperature

FIGURE 1



Cockpit Globe Temperature

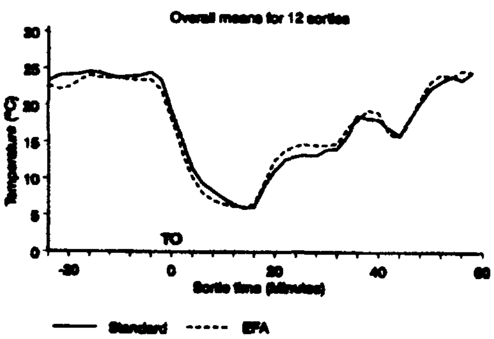
FIGURE 2



Cockpit WBGT

FIGURE 4

T_g showed a similar pattern with highest values on the ground during the third sortie of the day (45°C to50°C), falling to values between 27°C and 35°C at FL250, rising to 40°C to 45°C post flight (Figure 2). Cockpit humidity reflected in T_{wb} (Figure 3) was high during taxi and line up for take-off (circa 50%), fell rapidly to values below 10% at altitude and then steadily rose to reach values at the end of the sortie which were just below those occurring pre-flight. Overall thermal stress, quantified by T_{wbgt} (Figure 4), showed a pattern not significantly different for either the 2 AEA conditions nor for the time of day, with values between 25°C and 30°C prior to take-off, falling to 15°C at FL250, and rising to preflight levels by the end of the sortie.



Cockpit Wet Bulb Temperature

FIGURE 3

	Onset ($G.s^{-1}$)	Level (G)	Duration (s)
Turn 1	1.11	5.34	15.02
Turn 2	1.22	6.37	13.37
Turn 3	1.51	7.22	13.14
Turn 4	1.30	7.99	12.37

Means for High G Turns

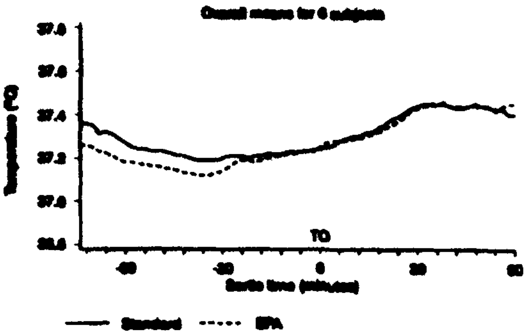
TABLE 4

G Environment. There were no significant effects of AEA on any of the three measures. The means are displayed in Table 4.

5. PHYSIOLOGICAL DATA

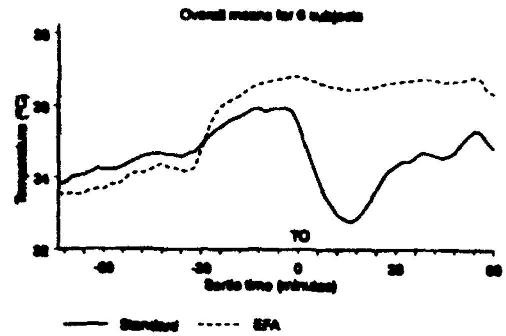
Rectal Temperature(T_{re}). The ANOVA showed that the EFA AEA did not produce a significant effect on T_{re} although this measure was influenced by stage in the sortie and by the time of day. The pattern of change of T_{re} was consistent for all sorties, involving a fall from the initial high value associated with donning the AEA, a steady rise from take-off time and a plateau after the ACM phase (Figure 5). Mean T_{re} was lower for the 0900h sortie than for the later sorties.

Skin Temperatures. The EFA AEA did not produce significant differences in skin temperatures of the biceps, forearm, abdomen, lower back, and calf



Rectal Temperature

FIGURE 5

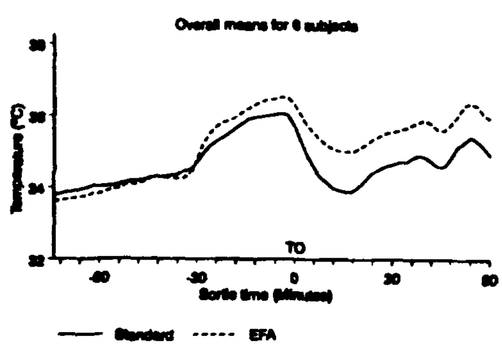


Chest Skin Temperature

FIGURE 7

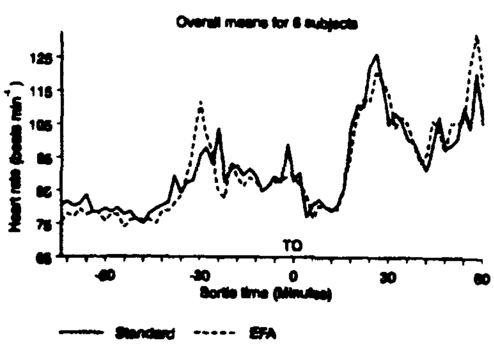
sites. However, the EFA AEA was associated with higher skin temperatures at the chest, back and upper thigh sites during the flight. All of the skin temperatures were affected by the changing environmental conditions to which the subjects were exposed. Skin temperatures at the chest and thigh sites varied with time of day. The Ramanathan mean skin temperature (T_{ram}; Figure 6), the means of the temperatures of the 4 torso sites and the mean of the temperature of the 2 leg sites were higher during flight when the EFA AEA was worn. The means of the temperatures measured at the arm sites were not different between the two assemblies. In both clothing assemblies, all skin temperatures showed a similar pattern throughout the measurement period. Temperatures rose following dressing to reach their highest values around take-off. Those sites not covered by the counter-pressure garments showed significant falls in skin temperature during the phase at FL250 followed by a steady rise to preflight values by the end of the sortie. The temperature of those areas covered by anti-G trousers and the CCPG remained significantly elevated throughout the sortie (Figure 7).

<u>Heart rate</u>. Heart rate (Figure 8) was high during walk-out and external checks (113beats.minute^{-1}), simulated ACM (113beats.minute^{-1}), and the 7.5 and 8 $+G_z$ turns (105beats.minute^{-1}). There was no effect of AEA on heart rate.



Mean Skin Temperature

FIGURE 6



Heart Rate

FIGURE 8

Time	Hawk AEA ($g.hr^{-1}$)	EFA AEA
0900h	170	230
1100h	240	330
1300h	250	290

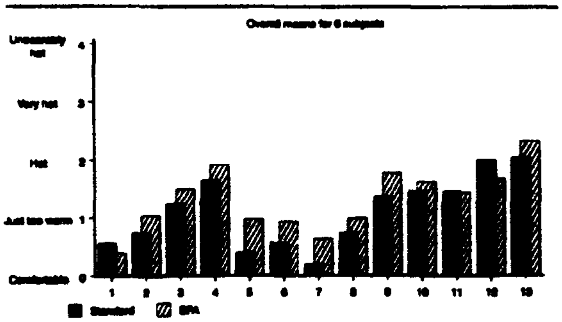
Sweat Secretion Rate

TABLE 5

Sweat Secretion. The calculated sweat secretion rate was investigated using ANOVA with 3 factors; subject, AEA and sortie. Main effects and the 2 interactions with fixed effects were considered. The results showed that sweat secretion was less with standard Hawk AEA than with EFA AEA. Mean sweat secretion rates are at Table 5.

6. SUBJECTIVE DATA

Thermal comfort was influenced by time of day, AEA worn, and by the stage of the sortie. Discomfort scores were least at 0900 and greatest at 1300 and were significantly higher following the 10 minute period prior to take-off and on completion of the sortie at engine shutdown. The EFA AEA was associated with greater discomfort only at the end of the transit period ($p<0.05$); the small differences seen at other stages were not significant (Figure 9). There was no effect of clothing on subjective fatigue but fatigue ratings were significantly higher following simulated ACM and for the rest of the sortie (Figure 10).

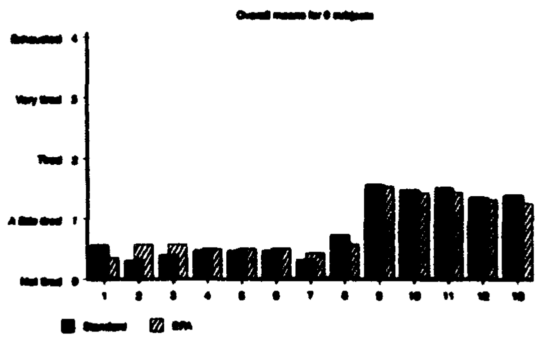


Thermal Comfort

FIGURE 9

Legend for Figures 9 and 10. Measures taken after:

1. Donning AEA.
2. External checks.
3. Engine start-up.
4. Line up for take off.
5. Transit.
6. 1st high G turn.
7. 10 min at FL250.
8. 2nd high G turn.
9. Simulated ACM.
10. 3rd high G turn.
11. 4th high G turn.
12. Landing.
13. Engine shut down.

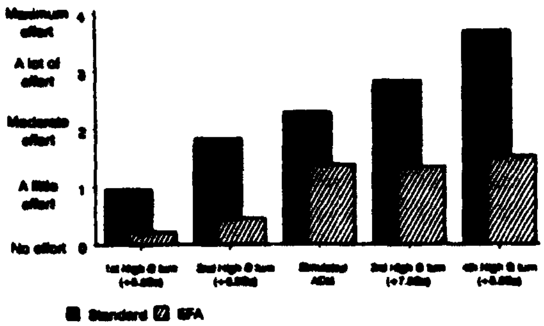


Fatigue

FIGURE 10

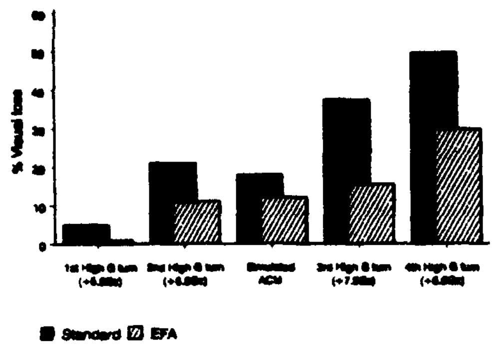
Associations between subjective thermal comfort and body temperatures were investigated using Analysis of Covariance. All the factors in the original model were included in the analysis, so that temperatures could be assessed as potential explanators. It was found that the only significant positive association was between T_{arm} (the mean of the 2 temperatures measured on the arm) and thermal comfort ($p<0.05$). However, T_{arm} was not a complete explanator, in that differences in thermal comfort between different points in the sortie were still significant.

Wearing the EFA AEA had a significant effect on both anti-G straining manoeuvre effort and subjective visual loss. Effort during all 4 turns and



AGSM Effort

FIGURE 11



Visual Loss

FIGURE 12

simulated ACM was significantly less when the EFA AEA was worn (Figure 11). At 6.5 $+G_z$ the mean effort rating when wearing the EFA AEA was 0.45 (ie between 'no effort' and 'a little effort') whereas in standard AEA the corresponding value was 1.85 (ie just less than 'moderate effort'). This difference was accentuated at 7.5 $+G_z$ where the values were 1.35 (ie just more than 'a little effort') and 2.85 (ie just less than 'a lot of effort') respectively, and at 8.5 $+G_z$ where the values were 1.54 (ie between 'a little effort' and 'moderate effort') and 3.72 (ie close to 'maximum effort'). Similarly, subjective visual loss was less during all 4 turns and simulated ACM when the EFA AEA was worn although this difference was only significant for the +7.5 and +8.5 G_z turns (Figure 12).

It was anticipated that there would be a link between G level and the 2 subjective measures, visual loss and AGSM effort. To investigate the nature of the association between these measures, mean recorded G level was treated as a covariate with different slopes for the two assemblies in an analysis of covariance for each of the two subjective assessments in which G turn number (ie. the level of $+G_z$ specified in the protocol), AEA worn, subject, and the interactions of these factors were treated as effects. The effect of the covariates was not demonstrably present for either subjective measure. However, if the factor defining G Turn - and thus the general expected G level - was removed with its interactions, different positive associations between visual loss and G level for the two assemblies were found. The gradient of the relationship between visual loss and G level for standard AEA was 16.06 ($p<0.01$) whereas that for EFA AEA was only 10.06 ($p<0.05$). A similar pattern was found for AGSM effort: 1.05 for standard AEA ($p<0.001$) and 0.52 for EFA AEA ($p<0.01$).

Analysis of comments collected during post-flight interview suggested that subjects experienced greater, but not intolerable, thermal discomfort whilst wearing the EFA AEA. Thermal discomfort was high during the ground phases of the sortie, and when outside the aircraft, regardless of AEA worn, but was intensified by the EFA AEA.

When asked to compare the level of $+G_z$ protection offered by the EFA AEA with that provided by the standard assembly under UK operating conditions, the subjects indicated that the EFA AEA provided somewhat to considerably more protection. There was some evidence to indicate a lowering of $+G_z$ tolerance associated with heat: two subjects reported that the standard AEA offered somewhat less protection under trial conditions than under UK conditions, and one subject, who had experience of the EFA AEA under UK conditions, reported that the assembly provided somewhat less protection

during the trial sorties.

There was considerable variation in subjects' experience of arm pain at high $+G_z$ whilst wearing the EFA AEA. Two subjects did not experience pain, and two reported only mild pain, occurring at levels of $+G_z$ of 6.5 and greater. Two subjects reported moderate to severe arm pain during simulated ACM and during turns involving levels of $+G_z$ of 6.5 and greater. Pain tended to be confined to, or to be more severe in, the left arm. Only one subject experienced arm pain whilst wearing the standard assembly; he reported moderate to severe bilateral pain when either assembly was worn.

A number of subjects reported restriction of mobility associated with the EFA AEA. Three commented that the full coverage anti-G trousers restricted mobility outside the aircraft; two subjects noted that movement of the upper body during simulated ACM was hampered by the chest counter-pressure garment.

When invited to indicate whether or not they had a preference for either AEA, all subjects expressed a preference for the EFA assembly, although two indicated that this applied only for exposure to $+G_z$ levels greater than 7; at lower levels of $+G_z$, the protection provided by the standard assembly was considered adequate, and an advantage was conferred by the AEA being less restrictive. Overall, the EFA assembly was felt to offer greater $+G_z$ protection, and made the profile easier and less tiring to fly, although one subject considered the arm pain associated with the assembly "a significant disadvantage."

7. DISCUSSION

This trial was designed to provide a thermal and $+G_z$ acceleration environment in which the protection provided by, and the thermal stress associated with, the EFA AEA could be assessed. The RAF IAM Hawk is authorised to attain $+9.5G_z$ during trial flying. 'Academic' high $+G_z$ turns (ie, turns flown in a standardized, reproducible way) in the Hawk aircraft do not reproduce the workload of true air combat nor does simulated ACM produce the very high levels of acceleration likely to be experienced in an agile combat aircraft such as EFA. Workload during the simulated ACM phase was controlled by the safety pilot in the rear seat and was made as demanding as possible, consistent with maintaining a reproducible level of effort. High $+G_z$ was provided by a series of academic turns during which visual loss and AGSM effort were measured. $+8.5G_z$ was chosen as the highest level to prevent the aircraft being accidentally over stressed by $+G_z$ levels above the authorized maximum. It was considered that the workload involved in resisting the effects of this level of acceleration are not significantly different from that involved at $+9.5G_z$, and that this level was adequate to assess the G protection provided by the 2 assemblies, especially in the 13^{o} upright seat of the Hawk. However, high $+G_z$ acceleration is very difficult to sustain in the Hawk because of limited engine thrust, a situation compounded by increasing altitude and high ambient temperature. In order to achieve $+7.5G_z$ and $+8.5G_z$ a considerable dive was required to obtain the required airspeed. It was impossible to maintain these high $+G_z$ levels for the intended 15s but virtually all the turns were held for more than 10s (Table 4), sufficient time for visual loss and cardiovascular compensation to occur. Table 4 shows that the first 3 turns were within $+0.3G_z$ of the level specified in the protocol but that the final, highest level turn was some $+0.5G_z$ less than the level specified in the protocol.

The environmental conditioning system (ECS) of the Hawk, although adequate for temperate climates, produces a significant thermal stress in warmer climates. The canopy must be closed

before engine start and the degree of cooling provided by the ECS when the engine is at low power setting is minimal. The Pilots' Notes authorize the use of 70% engine rpm expressly to provide more cooling, but this facility was not used in this trial. The ECS control setting was maintained in the middle of its operating range, partly to provide a consistent level of thermal stress between sorties, but also to prevent water vapour freezing in the system causing intermittent and unpredictable failures during the trial. The degree of thermal stress experienced by the trial subjects can be assessed by comparing the measured cockpit conditions with those predicted conditions for thermal comfort in the model developed by Richardson.(4) For this level of clothing insulation and the flight profile and environmental conditions experienced at RAF Akrotiri, a cockpit temperature of approximately 6°C would be required for comfort. If the actual mean cockpit conditions experienced during this trial are used to predict the mean comfort vote,(5) a value of approximately 6 is obtained equivalent to "Warm" on the 7 point ASHRAE comfort scale which is outside the recognised comfort region.

The time between canopy closure and take-off was approximately 15 to 20 minutes during which time the aircraft was taxied to the runway threshold. This period, which was associated with high levels of thermal stress (T_{db} 30 - 40°C; T_g 35 - 50°C) was, for most sorties, unnecessarily long. However, it was included in the flight profile to allow for the possibility of longer taxying times or other air traffic preventing take-off on time. In addition, a phase of ground operation of this nature could easily be a part of EFA development or operational flying. As a consequence of this arrangement, no take-off was more than 15 s away from the scheduled take off-time and, indeed, the subsequent phases of the sortie were all flown to within +/- 2 minutes of their scheduled times.

The 10 minute period at FL250 was associated with reduction in the level of thermal stress. This was included in the flight profile in order to assess the effect of a medium or high level transit, a likely component of an air combat sortie, but also to separate the effects of preflight thermal stress from that generated during simulated ACM and the subsequent high $+G_z$ turns.

The absence of any sortie sequence effect on the variables measured confirms that there was no systematic change in the environmental conditions through the trial and also that the subjects were adequately acclimatized. The results indicate that the EFA AEA was more thermally stressful and produced more thermal strain than the standard AEA as indicated by higher skin temperatures, greater sweat loss and decreased thermal comfort for part of the sortie. Skin temperatures were higher in those areas of the body covered by impermeable garments, reaching 37°C on the chest in some sorties (Figure 7), and it was noticeable that these areas did not benefit from the cooler and drier cockpit conditions which occurred at FL250. Despite this, with the exception of temperatures measured on the arm, there was no significant relationship between skin temperatures and thermal comfort. However, it is possible that thermal comfort is related more to general heat balance and that rate and direction of skin temperature change might be better predictors of this variable. Because of insufficient information about work load and consequential heat production, this hypothesis could not be tested in this analysis.

Core and skin temperatures are a manifestation of body heat content and are influenced by rates of heat production and loss. In this study there was no significant difference in mean rectal temperature between the two AEAs. However, mean skin temperatures, especially over the torso, were higher during the flight phase when the EFA AEA was worn.

However, this effect on heat loss may be partially offset by decreased metabolic heat production as a result of reduced AGSM effort when the EFA AEA is worn. Further studies are needed to measure metabolic rate in high G flight with and without enhanced G protection.

Although the differences in thermal comfort between EFA AEA and standard AEA in this trial were not great, at higher levels of environmental stress or when more insulative clothing (such as immersion suits or NBC AEA) is worn this effect may become more significant. Similarly, although sweat rates were not high enough to constitute a serious threat of dehydration, sweating was significantly greater with the EFA AEA, a difference likely to be accentuated at higher levels of thermal stress. Rectal temperature was unaffected by the AEA worn and remained within safe limits despite rising in response to the thermal stress imposed. A clear circadian rhythm was evident in measures of T_{re}. Subjective measures of fatigue reflected the level of work load through the sortie but were unaffected by the AEA worn.

These results indicate that despite the increased thermal stress associated with the EFA AEA, compensatory thermoregulatory mechanisms were operating effectively to maintain homeostasis. Furthermore, the EFA AEA provided superior anti-G protection, allowing +8 G_z to be tolerated with little or no straining effort. The degree of visual loss experienced during high G turns and simulated ACM was significantly reduced when the EFA AEA was worn. All subjects indicated a preference for the EFA AEA for ACM and high $+G_z$ flight.

Subjective assessments of AGSM effort whilst wearing the EFA AEA were higher than expected. Previous centrifuge work has shown that using the EFA Interim AEA with pressure breathing with G (PBG), $+8.3G_z$ can be tolerated without straining.(6) All the subjects in this study had received centrifuge training with PBG up to +7.4 G_z and during the trial were briefed to strain only if visual loss was experienced. However, subjects' comments indicated that these experienced Hawk pilots found it difficult to inhibit the automatic action of straining whilst pulling $+G_z$. Visual loss during the turns was only significantly different at the 2 highest levels of G. Experienced pilots report that, even when wearing standard AEA, visual loss would not be expected at $+5.5G_z$ and would be minimal at $+6.5G_z$ when flying the aircraft. The level of visual loss recorded whilst wearing the EFA AEA, which was greater than expected, may have been a consequence of this straining reducing the effectiveness of the PBG system. However, further research is required to test this hypothesis.

The analysis of the relationship between G level and the subjective measures of visual loss and AGSM effort indicate the presence of a general positive association, but fails to identify a direct association between the variation of the measures about generally prescribed values. However, G level, visual loss and AGSM effort are measures taken from a potential closed loop control system, in that if visual loss increases, G level might be decreased by the pilot. The relationship with AGSM effort is likely to be more complex since if visual loss supervenes, the pilot may either increase straining or relax the rate of turn thus reducing G level. Any direct open loop causative relationship is likely to be masked in measures taken from the closed loop system involving negative feedback by the pilot, and it is surmised that this is the explanation for the absence of the significance of the covariate in the analysis.

The occurrence of arm pain was variable but appeared to be consistent with previous experience of this AEA. The greater incidence in the left arm

may be due to the fact that with the left hand on the throttle, the left forearm is some 100mm lower than the right, a possible cause of arm pain being the rise in venous pressure that occurs in the forearm during PBG (unpublished RAF IAM data).

8. CONCLUSIONS

This trial demonstrated that wearing the prototype EFA Interim AEA in a warm climate was associated with an increased, but not unacceptable, level of thermal stress. The anti-G protection provided by the AEA was superior to that offered by the standard assembly and this benefit outweighed the cost to thermal comfort. However, these findings may not generalize to conditions where ambient temperatures are higher or where there is a requirement for highly insulative protective clothing.

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IMPLICATIONS OF CLIMATIC EXTREMES IN AIRCREW NBC OPERATIONS

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SUMMARY

The NBC protective equipment and facilities in service with UK forces must be used when an appropriate threat exists irrespective of climate. Modifications to the individual assemblies, including provision of heated ventilating air to the aircrew respirator and additional insulation in cold conditions together with means to increase loss of body heat in hot climates and combined with changes to procedures and adaptation of concepts of use; can minimise the impedance to effective air operations which may occur from the additive effects of wearing NBC protective equipment in climatic extremes.

INTRODUCTION

It is generally recognised that chemical warfare agents may be faced by NATO forces during future conflicts either in limited operations or in the less likely event of a major conflict. It is essential, therefore, that the protection standards for aircrew remain high and proficiency in the use of individual protective equipment (IPE) together with the procedures required to utilise the equipment on the ground and in the air must be maintained by regular exercises and practice. However, in the broader military scene the very threat of chemical (CW) attack already has a beneficial effect for the enemy such that friendly forces must expend time and resources to counter its effects even before it is used, and even though it may not, indeed, be used. These precautions cost us operational effectiveness. The problem is further compounded if the operations have to take place under extreme hot or cold weather conditions. Recent experience in the Persian Gulf and repeated trials in Arctic conditions have identified modifications to NBC protective equipment used by United Kingdom Forces and changes to procedures which can minimise the additional impediment to operational effectiveness caused by adverse weather.

The United Kingdom NBC protective system for aircrew comprises five different facets none of which can be isolated from the other in the operational scenario. These components of the defensive system are as follows:

(1) Aircrew Respirator,
(2) Below Neck Protective Assemblies,
(3) Ground Supply Systems,
(4) Aircraft Supply Systems, and
(5) Collective Protection Facilities (COLPRO).

Details of each of these components have previously been described (2, 5) and this paper considers the modifications which must be introduced in order to maintain the operational capability of aircrew in hot and cold climates. These modifications and changes to procedures are considered for each of the components of the Aircrew NBC Protective System.

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In general, operations from fixed air bases where carefully controlled environmental conditions can be maintained within the areas of collective protection and the aircraft used have effective environmental control systems which can maintain adequate thermal comfort, modifications to equipment and procedures are only required to ensure safe transit from the areas of collective protection to the aircraft and permit the wearer to carry out his pre-flight tasks prior to connection to the aircraft system. A much more difficult problem is posed for operations off-base where unhardened or portable collective protection facil .es are required and operations ·intained using aircraft, particul.rly helicopters, in which cabin conditioning facilities either do not exist or cannot be used to the full potential, eg "doors off" helicopter sorties in Arctic or Tropical (10) conditions. The implications of these "worst case" conditions on NBC protection are considered.

OPERATIONS IN COLD WEATHER CONDITIONS

Several trials, over a number of years, have been conducted by United Kingdom Forces in Arctic conditions (4, 10). These have contributed to the evolution of concepts of operations using forward bases equipped with unhardened collective protection facilities. Support of these facilities poses fairly major logistic problems and it is not the purpose of this paper to discuss how these problems might be overcome, but only to indicate the requirements of the individuals in these deployed sites.

Aircrew Respirator

The United Kingdom aircrew respirator which provides protection of the head and neck against CW agents needs no introduction and is known as the Aircrew Respirator NBC No 5 (AR5). It was developed some fifteen years ago (2) as an underhelmet respirator and is supplied by a ventilating flow of filtered gas so that a safety pressure is maintained within the respirator and a continuous flow of gas is provided through its interior. This continuous flow ensures that, even if a break in the seal occurs, ambient air will not be drawn into the respirator. It also plays an important part in preventing misting of the internal surfaces of the visual area. However, in cold conditions the flow of gas impinging on the skin may well cause cold injury. Without modification, the standard Aircrew Respirator NBC No 5, with filtered air supplied on the ground and in flight in helicopters, from a portable ventilator, is safe to use continuously only at temperatures higher than -15°C (5). Prolonged use below this temperature will result in serious cold injury or frostbite.

The modifications to the AR5 which have proved to be effective in preventing cold injuries caused by contact between certain areas of the respirator and facial skin are still under development and, although not yet fielded within the Service, have been identified as follows:

(1) Attachment of a shaped piece of fur-covered fabric to the lower edge of the internal aspect of the respirator faceplate and extending downwards to prevent direct contact of the cowl with the skin of the under-chin area.

(2) Redistribution of the gas flow through the visor compartment which is achieved by a minor modification to the deflector plate within the respirator. This modification also includes a lining of fur-covered fabric so that direct contact with the skin is prevented.

(3) The ventilating air supply to the respirator has to be heated, and this is achieved by an in-line heater installed close to the inlet to the hood. The electrical supplies (28 VDC) to the heater may be provided on the ground from a separate battery and in the air from aircraft power supplies. It is capable of raising the temperature of the gas supplied to the respirator by approximately 20°C.

Below Neck Assemblies

The shortcomings of an overgarment concept of NBC protective suit in the context of flight operations led to the development of a garment containing activated charcoal which is worn beneath the outer layer of current normal aircrew clothing assemblies. Thus, the NBC protective system integrates well with the standard cold weather clothing assembly of UK aircrew. However, until recently protection against post-escape immersion combined with NBC assemblies was unsatisfactory since the immersion protection suit (Mk 10) was worn external to all other items of equipment. Thus, once contaminated it had to be cut off and could not be re-used. An inner immersion coverall has now completed development, is in service and consists of a partial double layer, closely fitting coverall which is worn beneath the NBC coverall, but over the standard aircrew underwear and thermal insulation garments. Use of this garment provides an overwater winter aircrew NBC assembly (7).

Collective Protection

It is well recognised that the key to maintenance of air operations beyond 24 hours is the provision of collective protection (6). There is no doubt, however, that aircrew operating away from fixed bases without hardened facilities are at a serious disadvantage even if some form of portable collective protection is available. The portable collective protection must incorporate facilities to provide users with food, water, lighting and, most importantly, (in cold climates) heating, drainage etc. It must be capable of accommodating all the aircrew (albeit on a shift basis) and yet be easily and rapidly packed for transport in the event that a change of site is required. Several approaches to this problem have been described (3, 8) and the 'PORTON' liners adopted by UK Forces have been successfully utilised in temperate climates with appropriate air filtration units and tentage coverage. Such spartan facilities are very difficult to operate outside of a fixed building in Arctic conditions. The practical problems of Doffing/Donning contaminated clothing and entering and exiting collective protection outdoors, unprotected from Arctic weather, are self-evident. Other major problems, which can be generated by snow melted by the warm air flowing from the collective protection facility and later re-freezing when the air filtration units and associated heaters are turned off, may be virtually insurmountable and prevent subsequent re-use or dismantling of the facility if a site move is required.

The main operational penalties imposed by aircrew chemical defence equipment and procedures have been identified previously as arising from the encumbrance of the respirator and below neck assemblies (ie the IPE) on the ground (6). Not unexpectedly, when operating in cold weather conditions the additional bulk of equipment required to provide necessary thermal insulation, further impedes mobility of the head and neck and general body movements. Thus, the level of readiness and rapid reaction versatility which might be expected of forward operating bases cannot be readily achieved in cold

conditions when NBC defensive protection is worn and the other components of the protective system are utilised. Erection and dismantling of COLPRO facilities demands high physical activity and transport of the equipment can be a major logistics problem. Collective protection can, however, be satisfactorily established inside heated buildings and the development of appropriate concepts of operation and acquisition of the necessary skills to utilise adequately all of the facilities requires regular exercises in realistic conditions.

OPERATION IN HOT ENVIRONMENTS

The same NBC protective garments must be used in cold and hot conditions and the maintenance of air operations in hot environments, as it is in the cold, imposes major problems on aircrew whilst on the ground. Adequate air conditioning in areas of collective protection is essential and may be best achieved by erection of collective protection facilities inside already air conditioned buildings. If such a solution is not possible then suitable air conditioning units must be fitted to the air filtration units supplying the facilities. During operations in high ambient temperatures all of the normal precautions against development of heat illness must be taken and appropriate measures to modify these procedures introduced when the additional penalties of wearing NBC IPE are taken into account. The general measures which must be followed to minimise the thermal stress on aircrew would include procedures such as use of aircraft canopies to reduce solar heat input and reduction of aircrew pre-flight ground time outside air conditioned facilities to a minimum. Physical activity must also be minimised and means of achieving this can include transport to the aircraft, pre-flight inspections carried out by other competent aircrew and provision of adequate assistance with donning and doffing of the NBC IPE.

If adequate environmental control is not available on the aircraft, as often is the case in helicopter operations, then the aircrew must be made aware of the signs of decreased performance, eg impaired vigilance, decreased tracking ability, poor memory registration and perhaps impaired perception of the passage of time. Post-flight aircrew should be quickly moved to a cool environment and rehydrated. This may be a somewhat difficult procedure if adequate drinking facilities are not available in the respirator. These drinking facilities must be usable where a vapour hazard exists and provide sufficient volume at an adequate flow to satiate the sensation of thirst. No other modifications to the AR5 have been introduced. The through flow of ventilating air does, however, provide some psychological benefit although contributing little to reduction of the thermal load.

The Environmental Control Systems (ECS) in modern aircraft are generally capable of producing comfortable thermal environments in all flight conditions at temperatures up to about 45°C and relative humidity of approximately 25%, thus with effective ECS and compliance with the general measures already outlined, experience has shown that little additional impairment of aircrew performance will occur when the stresses of hot environments are added to those of wearing NBC IPE.

In the context of helicopter operations, however, where environmental control within the helicopter may be non-existent, maintenance of thermal equilibrium, or at least comfort, is essential not only on the ground but also throughout the operational sortie. In these situations increased loss

of body heat must be induced. The most effective method of achieving this is by using a Personal Conditioning System. As a consequence of the recent conflict in the Persian Gulf development of aircrew microclimate conditioning was given added impetus, and although hurriedly conducted, many experimental studies were able to demonstrate the benefits of Liquid Conditioned Vests (LCV). A typical system examined in the UK utilised a 2-litre block of ice as a heat sink with .e conditioning fluid being circu ced by a small DC pump powered by a rechargeable battery (9). Each ice block provided 150W of cooling for about 60 minutes. This is essentially the system employed by the Canadian Forces and is manufactured by EXOTEMP Ltd of Pembroke, Ontario (1). A series of experiments, in which the daily average temperatures for the Gulf and the appropriate resulting cockpit conditions simulated, were conducted in the Laboratory (9) . The experiments, although aimed at examining the effectiveness of Liquid Conditioning when wearing standard and NBC aircrew equipment, required each subject, as a control, to repeat the exposures wearing standard AEA without cooling. This control condition demonstrated that the level of thermal stress used in the experiments produced an unacceptable level of thermal strain with rectal temperatures of 39°C, mean skin temperatures greater than 30°C, heart rates in excess of 120 beats per minute and sweat rates double the rate measured in the microclimate conditioned subjects. This physiological state is extremely uncomfortable and, at the very least, is a distraction which will degrade performance and may constitute a severe flight safety hazard. Conversely, in all the simulations in which personal conditioning was employed core temperatures never rose above 38°C and although observed to be slowly rising did not show the unchecked rate of rise seen in unconditioned controls. Mean skin temperatures were much lower, particularly on the torso, contributing to the overall sense of comfort reported by the subjects. Some conditioned subjects experienced hot extremities and cool torsos and the effect of this abnormal distribution of skin temperature is not known, although it does not appear to have been a problem in these studies. Recorded heart rates in conditioned subjects were lower and appropriate to the activity level.

It was concluded from these experiments that under simulated operational conditions a liquid conditioning system considerably reduces thermal strain and improves the subjects' ability to operate in a thermally stressful environment. Further detailed work is needed to determine conditioning fluid flow rates, temperatures etc and optimum liquid conditioned vest design and other parameters associated with optimum performance of the cooling system. Nevertheless, at the present time liquid conditioned garments, particularly when the cooling fluid can be provided from a source independent of aircraft supplies, will make major contributions to the ability of aircrew to adequately maintain operations in a hot environment. The logistic problems, however, of supplying ice packs, where this is the means employed for providing a heat sink, requires the procurement and appropriate distribution of large capacity ice producing and storage facilities.

Integration of the LCV with the other below neck garments and the procedures necessary to allow re-use of contaminated outer equipment must also be developed to ensure operational effectiveness. Satisfactory integration with UK aircrew NBC assemblies was achieved by introduction of a cover [made in

NBC protective material] for the supply pipes and connectors. Donning and Doffing procedures within unhardened COLPRO were devised and validated by appropriate trials.

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The Environmental Symptoms Questionnaire: Assessing Reactions to Environmental Extremes in Military Operations

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1. SUMMARY

The Environmental Symptoms Questionnaire (ESQ) was developed to aid in the standardized assessment of symptoms experienced by individuals exposed to environmental extremes. It was used initially to delineate the symptoms of acute mountain sickness, but has since evolved into a more comprehensive tool for assessing subjective reactions to ambient heat and cold, to diet, physical exercise, and medications. The ESQ has also been made more reliable and user friendly by revision, addition and removal of certain items, and by compression of the initial scale values. Factor analysis of responses has identified several meaningful symptom clusters, and has provided a useful technique for scoring those clusters under both laboratory and field conditions. Studies utilizing the ESQ under various environmental extremes are summarized and reviewed. Current administration and scoring methods are presented.

2. INTRODUCTION

Exposure to extreme weather has had dire consequences for military forces throughout history. Besides mortality due to battle injuries and wounds, countless deaths and casualties have been caused by exposure to severe weather conditions; mainly cold, heat, wind and high altitude. The effects of severe cold on troops are exemplified by the disastrous Russian winter campaigns of the Napoleonic armies (1), and again of the Hitler Wehrmacht (2). Tropic and desert heat were major incapacitating factors in World War II, while heat and humidity caused still other difficulties for military operations in Viet Nam. Altitudes above 10,000 feet pose still other problems through the development of acute mountain sickness; more severe exposures can result in an incapacitating syndrome called high altitude pulmonary edema, or the potentially fatal cerebral edema. Even moderately severe environmental conditions can also create operational problems by affecting troop performance, altering attitudes and mood states, and disrupting morale (3,4,5).

Although the common human reactions to environmental extremes are well recognized, accurate measures of those reactions have been difficult to obtain. Routine casualty reports and medical treatment records invariably contain a considerable amount of errors and inaccuracies (6). Diaries and anecdotes of personal experiences (7) are also subject to bias and error in both reporting and recording (8) because they are inherently qualitative and/or non-specific. In addition, maintaining scientific measurement standards and controls under field conditions is very difficult. Thus, historically there have been only a few accurate scientific accounts of subjective reactions to severe weather, while quantitative measures of the severity of reactions are almost nonexistent.

One of the first attempts to generate objective data on environmental symptomatology was by McFarland. He used questionnaires in a series of high altitude studies to relate physiological symptoms to behavioral reactions (9,10). However, these questionnaires were limited in scope, and were never standardized. In 1965, Evans (11) tried to document the development of acute mountain sickness symptoms using a scale called the General High Altitude Questionnaire (GHAQ). This scale did identify and quantify some of the typical symptoms, but it had several inherent shortcomings and was not standardized for scoring.

To improve on these deficiencies, Sampson (12) developed the Environmental Symptoms Questionnaire (ESQ). Descriptive phrases of all known altitude symptomatology were first collected through an extensive literature review back to 1736 (7). The accumulated symptom phrases were then organized into clusters related to the aspects of each symptom (e.g., headache: head pressure, head throbbing, etc.). Finally, 52 questionnaire items were composed to reflect the derived symptom clusters, along with a 9-point rating scale to estimate symptom intensity.

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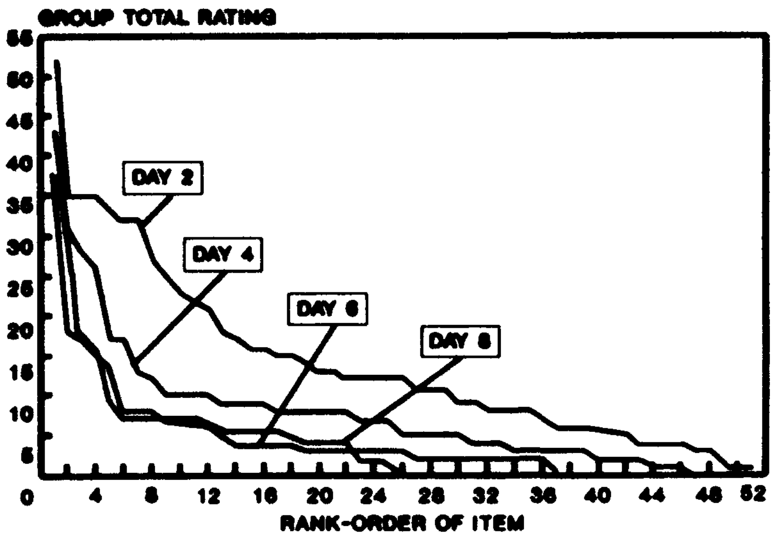

Figure 1. Rank orders of the summated totals of intensity ratings for ESQ items during successive days of altitude exposure

The ESQ was field-tested (13) in a high altitude study (4300 m) comparing it to the GHAQ, in which 12 military volunteers completed both questionnaires on alternate days over an 8-day period of exposure. The ESQ not only showed general agreement with the GHAQ, but also gave a broader picture of the development of high altitude symptomatology.

In Figure 1, the summated totals of all intensity ratings made by the group for each ESQ item are shown arranged in rank order of total rating magnitude for successive days at altitude. These totals indicate that the overall group reaction to continued altitude exposure followed the typical development profile of acute mountain sickness, in that the severity of reactions developed rapidly during early exposure, and then diminished gradually. Also, the highest intensity ratings occurred for items reflecting the characteristic symptoms of acute mountain sickness, although the nature of the individual symptoms are not described in the graph.

Based on several subsequent studies, the ESQ was improved and broadened to reflect not only altitude reactions, but also responses to heat, cold, and effects of certain military operational conditions, primarily protective clothing and the use of medications.

The ESQ was evaluated further in another field study at altitude (14); also, in studies of the effects of prolonged overseas flight on health and physical performance (15,16), and of the effects of continued load-carrying over several days (17).

Based on the total ESQ symptom data available to that point, a factor analysis was then performed to identify clusters of related items. Five principal symptom clusters emerged from this analysis: (1) exertion, (2) fatigue, (3) headache-nausea, (4) eye, ear, nose, throat symptoms (EENT), and (5) wellness. Weighted scoring for symptom clusters was also developed, as well as standardized instructions and procedures for administration.

Based on the factor analysis and the available data, the questionnaire then was revised to include some additional altitude reactions and some symptoms of exercise stress; also, confusing or ambiguous items were reworded. The resulting form is the current version containing 67 items spanning a wide range of environmental reactions, as well as symptoms of heat exhaustion, dehydration, cold exposure, and the common cold. A facsimile of this version is shown in Appendix A.

Based on data subsequently obtained using the revised ESQ in several altitude studies involving a large test population, another factor analysis was performed (18). Nine meaningful and reliable factors were identified: (1) acute cerebral mountain sickness (AMS-C); (2) acute respiratory mountain sickness (AMS-R); (3) ear, nose, and throat symptoms (ENT); (4) cold stress; (5) distress; (6) alertness; (7) exertion; (8) muscle discomfort, and (9) fatigue. The requisite symptoms and weights for each factor, as well as the formulas for computing each of the nine factors (18,19), are shown in Appendix B.

The AMS-C and AMS-R factors are relatively independent dimensions of AMS. ENT refers to ear, nose and throat symptoms, while the cold stress factor involves reactions to being cold. Distress is a complex combination of both respiratory and psychological mood symptoms. Muscle discomfort reflects symptoms due to exercise, and fatigue includes feelings of weakness and tiredness.

3. RESEARCH APPLICATIONS OF THE ESQ

The ESQ is now an effective instrument for measuring reactions to severe heat and cold, as well as to high altitude. One example of its sensitivity to heat effects is a study of the influence of heat, exercise, and wearing of chemical protective clothing on dehydration and fluid-electrolyte balance (20). In this study, 15 soldier volunteers walked a treadmill for up to six hours under moderately hot ambient conditions (85.1°F/33%RH) while wearing the battle dress uniform (BDU) or three experimental modifications of the MOPP-IV chemical protective ensemble. The ESQ was administered immediately before and after the exercise period. All participants completed the exercise while wearing the BDU, but less than 40 per cent were able to complete it while wearing the MOPP-IV ensembles, indicating the severity of the heat load under MOPP-IV conditions. The ESQ items were grouped into six categories related to heat and exercise for purposes of interpretation: weariness, headache, heat reactions, body aches, light-headedness, and thirst. The vast majority of item severity ratings in the pre-exercise condition fell into the slight to moderate categories, with the MOPP-IV conditions showing slightly higher ratings than the BDU. However, after exercise there was a marked increase in moderate to severe rating categories under all MOPP-IV conditions, but only slight increases under the BDU condition. The ESQ results corresponded closely to the demonstrated abilities of the participants to complete the exercise period under the respective clothing conditions, and also to their observed water consumption.

In two other studies designed to complement each other, the ESQ was used to appraise symptomatic reactions to nerve agent antidote (2 mg atropine/600 mg 2-PAM chloride) and hot-humid conditions while wearing the BDU and the MOPP-IV chemical protective ensemble (21). In one study, 15 soldier volunteers received either the drug or a placebo double-blind, and performed a selected battery of psychomotor and cognitive tasks for up to six hours while wearing the BDU under contrasting moderate (70°F/30%RH) and hot-humid (95°F/60%RH) ambient conditions. In the other study, eight soldier volunteers underwent the same test conditions while wearing the MOPP-IV chemical protective ensemble, except that the moderate heat condition was adjusted to 55°F/30%RH to offset the inherent heat load of the MOPP-IV system. The ESQ was administered in both studies at the termination of each test session. All participants completed all conditions while wearing the BDU; but none were able to complete the hot-humid condition while wearing the MOPP-IV. The ESQ ratings in the two studies proved to be commensurate with the respective heat loads, in that the intensity of ratings under the heat conditions and while wearing the heat-encapsulating MOPP-IV ensemble were much higher overall than while wearing the BDU. Also, the focus of symptom ratings under heat conditions shifted toward items related to heat and discomfort.

An example of use of the ESQ under cold conditions is a cold weather field training exercise involving 59 military participants (22). In this study, the ESQ was administered during and at termination of the rigorous training. Its purpose was to assess the development of symptomatology; and to compare symptoms and accompanying mood states with the participants' prior attitudes toward cold weather and their expectations of liking the exercise. The ESQ items were found to cluster into five significant domains related to rigorous training in the cold, as shown in Table 1 along with related reliability indexes (Cronbach's Alpha).

TABLE 1

COLD-RELATED ESQ SYMPTOM DOMAINS AND RELIABILITY INDEXES

ESQ DOMAIN	ESQ ITEMS	RELIABILITY (CRONBACH ALPHA)
Cold Discomfort	Cold hands	0.90
	Cold feet	
	Felt chilly	
	Shivering	
	Numbness	
Muscle Discomfort	Muscle cramp	0.80
	Muscles tight/stiff	
	Legs/feet ached	
	Hands,arms,shoulders ached	
	Back ached	
Cardiopulmonary Discomfort	Short of breath	0.76
	Hard to breathe	
	Hurt to breathe	
	Heart beating fast	
	Heart pounding	
	Chest pain	
	Chest pressure	
Tiredness	Felt weak	0.70
	Felt tired	
	Felt sleepy	
Well-being	Felt good	0.86
	Felt alert	
	Felt wide-awake*	

* New item not on prior versions

Multiple regression analyses indicated that the ESQ domains were significantly related to the participants' expected dislike of cold weather training; also, symptom ratings increased with continued days of training. In this study, the ESQ accurately reflected the development of cold weather symptomatology, and the influence of the participants' prior attitudes toward cold weather exposure.

The ESQ has been used successfully to document environmental symptomatology in laboratory studies, military field exercises, mountaineering expeditions, and operation of high-altitude astronomical observatories. It has functioned effectively when translated into the German, French, and Chinese languages, and has accurately reflected symptomatology post hoc using a version in the past tense (21).

A comprehensive annotated review of all published laboratory and field study findings involving use of the ESQ has been conducted by Sampson, Kobrick, and Johnson (23). The published literature shows that the ESQ has corresponded consistently to medical and physiological measures, physician ratings, and clinical interviews in studies where those types of data were obtained. Factor analysis has identified unambiguous item clusters that reflect multidimensional aspects of a number of important symptoms, indicating that the ESQ reflects true environmental reactions rather than measurement artifacts or testing bias.

4. OPTIMUM USE OF THE ESQ

Standardized administration of the ESQ is essential to ensure valid and and reliable results. Questionnaires should be reviewed soon after completion and checked with respondents when possible, especially when the ESQ is given repeatedly throughout a study. Inconsistent responses should be verified for accuracy.

Standard scoring factors are now available for two types of acute mountain sickness (cerebral and respiratory), ear-nose-throat discomfort, cold stress, distress, alertness, exertion, muscle discomfort, and fatigue. Scoring based on those factors provides more accurate and reliable measures of symptomatology. Each measure is calculated by multiplying the relevant item rating by the factor weight of the item, summing these products, and dividing by the sum of the factor weights for that measure (see Appendix B). Factor-weighted scores have the added advantage of allowing comparison of results across studies using these same measures.

The ESQ was designed to be a unitary device, although sub-sets of the total items have also been used with reasonable success. However, use of item sub-sets can cause problems in interpretation, due to changes in context from those of the total questionnaire. Using the entire instrument also allows for identification of potentially confounding variables; (e.g., if ENT symptoms are caused by an upper respiratory infection rather than by an environmental condition). Thus, the entire inventory should be used whenever possible.

As new databases are developed, factor analysis will provide continued verification of the reliability of factors which have already been identified. Unless dramatically significant differences in clusters and weights are obtained, the scoring procedures outlined here should not be altered. The value of standardized measures and procedures used successfully over several studies will far outweigh any minor improvements in factor structure resulting from new types of analyses.

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APPENDIX A
THE ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE

	NOT AT ALL	SLIGHT	SOME-WHAT	MODERATE	QUITE A BIT	EXTREME
1. I FEEL LIGHTHEADED	0	1	2	3	4	5
2. I HAVE A HEADACHE	0	1	2	3	4	5
3. I FEEL SINUS PRESSURE	0	1	2	3	4	5
4. I FEEL DIZZY	0	1	2	3	4	5
5. I FEEL FAINT	0	1	2	3	4	5
6. MY VISION IS DIM	0	1	2	3	4	5
7. MY COORDINATION IS OFF	0	1	2	3	4	5
8. I'M SHORT OF BREATH	0	1	2	3	4	5
9. IT'S HARD TO BREATHE	0	1	2	3	4	5
10. IT HURTS TO BREATHE	0	1	2	3	4	5
11. MY HEART IS BEATING FAST	0	1	2	3	4	5
12. MY HEART IS POUNDING	0	1	2	3	4	5
13. I HAVE CHEST PAINS	0	1	2	3	4	5
14. I HAVE CHEST PRESSURE	0	1	2	3	4	5
15. MY HANDS ARE SHAKING OR TREMBLING	0	1	2	3	4	5
16. I HAVE MUSCLE CRAMPS	0	1	2	3	4	5
17. I HAVE STOMACH CRAMPS	0	1	2	3	4	5
18. MY MUSCLES FEEL TIGHT OR STIFF	0	1	2	3	4	5
19. I FEEL WEAK	0	1	2	3	4	5
20. MY LEGS OR FEET ACHE	0	1	2	3	4	5
21. MY HANDS, ARMS, OR SHOULDERS ACHE	0	1	2	3	4	5
22. MY BACK ACHES	0	1	2	3	4	5
23. I HAVE A STOMACH ACHE	0	1	2	3	4	5
24. I FEEL SICK TO MY STOMACH (NAUSEOUS)	0	1	2	3	4	5
25. I HAVE GAS PRESSURE	0	1	2	3	4	5
26. I HAVE DIARRHEA	0	1	2	3	4	5
27. I'M CONSTIPATED	0	1	2	3	4	5
28. I HAVE TO URINATE MORE THAN USUAL	0	1	2	3	4	5
29. I HAVE TO URINATE LESS THAN USUAL	0	1	2	3	4	5
30. I FEEL WARM	0	1	2	3	4	5
31. I FEEL FEVERISH	0	1	2	3	4	5
32. MY FEET ARE SWEATY	0	1	2	3	4	5
33. I'M SWEATING ALL OVER	0	1	2	3	4	5
34. MY HANDS ARE COLD	0	1	2	3	4	5
35. MY FEET ARE COLD	0	1	2	3	4	5
36. I FEEL CHILLY	0	1	2	3	4	5
37. I'M SHIVERING	0	1	2	3	4	5
38. PARTS OF MY BODY FEEL NUMB	0	1	2	3	4	5
39. MY SKIN IS BURNING OR ITCHY	0	1	2	3	4	5
40. MY EYES FEEL IRRITATED	0	1	2	3	4	5

APPENDIX A
THE ENVIRONMENTAL SYMPTOMS QUESTIONNAIRE

	NOT AT ALL	SLIGHT	SOME-WHAT	MODERATE	QUITE A BIT	EXTREME
41. MY VISION IS BLURRY	0	1	2	3	4	5
42. MY EARS FEEL BLOCKED UP	0	1	2	3	4	5
43. MY EARS ACHE	0	1	2	3	4	5
44. I CAN'T HEAR WELL	0	1	2	3	4	5
45. MY EARS ARE RINGING	0	1	2	3	4	5
46. MY NOSE FEELS STUFFED UP	0	1	2	3	4	5
47. I HAVE A RUNNY NOSE	0	1	2	3	4	5
48. I'VE BEEN HAVING NOSE BLEEDS	0	1	2	3	4	5
49. MY MOUTH IS DRY	0	1	2	3	4	5
50. MY THROAT IS SORE	0	1	2	3	4	5
51. I'VE BEEN COUGHING	0	1	2	3	4	5
52. I'VE LOST MY APPETITE	0	1	2	3	4	5
53. I FEEL SICK	0	1	2	3	4	5
54. I FEEL HUNGOVER	0	1	2	3	4	5
55. I'M THIRSTY	0	1	2	3	4	5
56. I FEEL TIRED	0	1	2	3	4	5
57. I FEEL SLEEPY	0	1	2	3	4	5
58. I COULDN'T SLEEP WELL	0	1	2	3	4	5
59. MY CONCENTRATION IS OFF	0	1	2	3	4	5
60. I'M MORE FORGETFUL LATELY	0	1	2	3	4	5
61. I FEEL WORRIED OR NERVOUS	0	1	2	3	4	5
62. I FEEL IRRITABLE	0	1	2	3	4	5
63. I FEEL RESTLESS	0	1	2	3	4	5
64. I'M BORED	0	1	2	3	4	5
65. I FEEL DEPRESSED	0	1	2	3	4	5
66. I FEEL ALERT	0	1	2	3	4	5
67. I FEEL GOOD	0	1	2	3	4	5

APPENDIX B
SCORING WEIGHTS FOR THE ESQ FACTORS*

Factor 1: Cerebral Acute Mountain Sickness (AMS-C) = F1/5.189

where: F1 = (I1 x .489) + (I2 x .465) + (I4 x .446) +
(I5 x .346) + (I6 x .501) + (I7 x .519) +
(I19 x .387) + (I24 x .347) + (I52 x .413) +
(I53 x .692) + (I54 x .584)

Factor 2: Respiratory Acute Mountain Sickness (AMS-R) = F2/7.138

where: F1 = (I2 x .312) + (I8 x .745) + (I9 x .763) +
(I10 x .734) + (I17 x .516) + (I22 x .686) +
(I23 x .744) + (I24 x .691) + (I46 x .534) +
(I48 x .578) + (I58 x .355) + (I65 x .480)

Factor 3: Ear-Nose-Throat = F3/4.307

where: F3 = (I3 x .302) + (I39 x .367) + (I42 x .441) +
(I43 x .300) + (I44 x .759) + (I45 x .784) +
(I46 x .329) + (I49 x .470) + (I50 x .555)

Factor 4: Cold Stress = F4/4.699

where: F4 = (I15 x .358) + (I19 x .331) + (I28 x .447) +
(I31 x .364) + (I34 x .642) + (I35 x .737) +
(I36 x .720) + (I37 x .580) + (I61 x .520)

Factor 5: Distress = F5/5.404

where: F5 = (I10 x .315) + (I13 x .566) + (I14 x .540) +
(I51 x .523) + (I53 x .373) + (I56 x .348) +
(I57 x .318) + (I61 x .379) + (I62 x .546) +
(I63 x .525) + (I64 x .492) + (I65 x .479)

Factor 6: Alertness = F6/3.214**

where: F6 = (I56R x .314) + (I57R x .300) + (I58R x .379) +
(I59R x .351) + (I65R x .300) + (I66 x .783) +
(I67 x .787)

Factor 7: Exertion = F7/3.377

where: F7 = (I1 x .371) + (I8 x .321) + (I9 x .419) +
(I10 x .351) + (I11 x .573) + (I12 x .505) +
(I13 x .471) + (I19 x .366)

Factor 8: Muscle Discomfort = F8/3.466

where: F8 = (I16 x .402) + (I18 x .594) + (I19 x .307) +
(I20 x .492) + (I21 x .406) + (I22 x .303) +
(I25 x .317) + (I38 x .315) + (I55 x .330)

Factor 9: Fatigue = F9/4.958

where: F9 = (I1 x .384) + (I4 x .418) + (I5 x .416) +
(I19 x .492) + (I40 x .398) + (I41 x .304) +
(I47 x .319) + (I55 x .371) + (I56 x .665) +
(I57 x .579) + (I58 x .300) + (I59 x .312)

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* I refers to Inventory Item numbers

** Items marked R must be reverse-scored before multiplication by the factor (0=5; 1=4; 2=3; 3=2; 4=1; 5=0), because those items are negatively-stated.

EFFECTS OF THREE HYDRATION BEVERAGES ON EXERCISE PERFORMANCE DURING 60 HOURS OF SIMULATED DESERT EXPOSURE

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SUMMARY

Without adequate hydration, profound heat stress and dehydration can occur in military forces operating in hot environments. The purpose of this study was to evaluate the effectiveness of three beverages on temperature regulation, cardiovascular response, and work performance during prolonged heat exposure. Nine male subjects, attired in standard military combat uniforms, lived in a climatic chamber for 3 days (60 h) in simulated desert conditions varying from 25 to 45 °C, 20% relative humidity. Three submaximal treadmill exercise bouts (40 min at 4.8 km/h, 0% grade) were performed at 4-h intervals each day. Subjects randomly consumed three beverages: (1) a water placebo of water, citric acid, and aspartame (WP); (2) a 5% carbohydrate drink containing water, citric acid, sucrose, fructose, and electrolytes (CE); and (3) a 4% carbohydrate drink containing water, citric acid, sucrose, glucose, electrolytes, pyruvate, and 1% glycerol (CEG). Subjects drank only one of the three beverages *ad libitum* during the 60 h but were encouraged to drink every 15 min during exercise. Each subject tested all three beverages in a double blind, repeated-measures experimental design. Sweat rate (SR), core (rectal) temperature (Tre), average skin temperature (Tsk), heart rate (HR), oxygen consumption (VO_2), and subjective ratings of perceived exertion (RPE) were recorded during exercise. Body temperatures and metabolic parameters remained within expected physiologic limits during 60 h of simulated desert conditions. During exercise, RPE and HR were similar for all beverages, but VO_2, Tre, Tsk, and SR differed among beverages. During the 3rd exercise session on all days, VO_2 was higher for CE than CEG and WP; CEG tests had the lowest VO_2 on the 2nd and 3rd days. Rectal temperature was lower with CE and CEG than with WP on the 2nd and 3rd exercise periods of each day. Skin temperatures were different during the second exercise period on all three days. Exercise sessions with CEG produced the highest SR. We conclude that carbohydrate-electrolyte beverages, preferably with a small amount of glycerol, may provide beneficial physiological responses during exercise in hot-dry conditions during the first 24 h of exposure. However, water alone appears to provide adequate hydration for working in desert conditions over extended periods of time.

INTRODUCTION

Temperature regulation and work performance in the heat are critically dependent on the state of hydration of the body (1). When fluid requirements are high and fluid loss exceeds intake, a deficit in body water occurs. As hypohydration occurs, plasma volume decreases. Hypohydration leads to elevated core temperatures and heart rates (2) and decreased sweat rates and cutaneous blood flow (2,3), adversely affecting work performance (4,5). Cognitive performance is also negatively affected by hypohydration (6,7).

With unstable world situations, the rapid deployment of military forces to hot, hostile environments without the benefits of acclimatization is a reality. Personnel may not have the opportunity to fully acclimatize to the heat before commencing operations. The increase in military operations in Southwest Asia in the past two years, encountering both hot dry and hot humid environments, has raised the awareness of the potential debilitating effects of inadequate or uncontrolled hydration. Military personnel have been found to voluntarily dehydrate 2% of body weight when acclimatizing to desert environments (8-10). A water loss of 2-6% of body weight may result in feelings of general discomfort, dizziness, irritability, fatigue, and apathy (11), degrading morale, discipline, and performance (12) rendering a military unit ineffective. A decreased appetite and an unreliable thirst mechanism contribute to the problem despite the availability of adequate fluids for consumption. Compliance with published drinking schedules is not always practical or strictly enforced. Nonetheless, dehydration can be prevented by matching fluid consumption to fluid lost through sweating.

Prolonged exercise in the heat exacerbates the depletion of muscle glycogen stores in the body and increases fluid loss through sweating (13). Beverages containing simple sugars and/or glucose polymers have been used in attempts to maintain blood glucose levels, reduce fluid loss, and enhance exercise endurance (14-16). Drinks containing various combinations of glucose, glucose polymers, electrolytes, and glycerol have been evaluated during short-term heat exposure with exercise protocols in the laboratory and field (8,10). When formulated into an isotonic

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solution, carbohydrate beverages have been shown (17,18) to maintain plasma volume at levels higher than those obtained with water consumption during exercise. In one study (19), however, these effects were accompanied by gastric distress and compromised physiologic function. Typically, carbohydrate beverages do not empty from the stomach as rapidly as water and may therefore produce gastric distress in some individuals. As the content of carbohydrates and/or the osmolality of the beverage increases, the rate of absorption and gastric emptying decreases (20). The major differences among studies of such fluids have been in the formulation of the beverages and environmental temperatures used for evaluation. Likewise, information is scarce concerning the physiological consequences or sustained effectiveness of long-term consumption of carbohydrate drinks. Many questions remain as to which beverage is ideal for personnel working in desert conditions, and what quantity should be consumed to maintain peak performance and health.

Glycerol ingestion prior to exercise has been evaluated as one mechanism for increasing both plasma volume and osmolality to improve temperature regulation through water conservation. Glycerol is a hyperhydrating agent that is rapidly absorbed, is evenly distributed among body fluid compartments, is a natural metabolite, is osmotically active, is well tolerated, and is safe at an oral dose of 1 g/kg body weight every 6 h (21). Lyons, Riedesel, Meuli, and Chick (5) have shown decreased urine output, increased sweating, and decreased rectal temperatures resulting from ingestion of 1 g/kg body weight of glycerol in 21.4 ml/kg water during a 4-h protocol. Another study (22) indicated that this effect persists past 4 h although plasma glycerol concentrations decreased to preingestion levels. However, Murray (23) observed no substantial metabolic, hormonal, or physiological advantages to the consumption of solutions containing 4 or 10% glycerol during exercise. No previous study has evaluated the cumulative effects of repeated glycerol administrations in a hot climate with exercise.

The purpose of this study was to test the effects of three different beverages on work performance during prolonged exposure (60 h) to simulated desert conditions. We conducted a limited series of extended duration trials with repeated administrations of selected fluids to evaluate the effectiveness of those fluids in maintaining hydration and extending or enhancing performance under environmental conditions similar to summer conditions in Southwest Asia. Our hypothesis was that carbohydrate-electrolyte drinks would perform better than water alone, and that a carbohydrate-electrolyte drink with a small amount of glycerol would prove most beneficial for temperature regulation and cardiovascular response during exercise in the heat. Endpoints evaluated in this report are oxygen consumption, core body temperature, sweat rate, skin temperature, heart rate, and a subjective rating of perceived exertion.

METHODS

Nine male subjects ranging in age from 22 to 29 (average 24) years volunteered for this study. Each subject was briefed on the details and possible hazards of the study before completing an informed consent form. All subjects received a physical examination including a health record screening for any history of hypersensitivity to heat. None of the subjects were acclimatized to hot, dry conditions at the time of the study. All sessions were conducted during February, March, and April 1991.

The temperatures and humidity for this study were selected and controlled to simulate typical desert conditions in Southwest Asia during the summer months. The relative humidity was approximately 20% and the dry bulb temperature was regulated between 25 and 45 °C as illustrated in Figure 1.

All tests were conducted in two adjacent environmental chambers each with separate temperature controls. The larger of the two rooms (3 x 4.8 m) housed all of the test equipment, while the smaller room (2.4 x 2.4 m) served as the sleeping quarters. The temperature in the main compartment was controlled by a Honeywell Single Vane controller. The bunk room temperature was passively controlled by an open door to the main test chamber. Humidity was reduced with a dehumidifier.

Groups of three subjects were tested over the 3-day (60 h) exposure. Each subject performed the test on three occasions with a minimum of 10 days separating each of the three 3-day trials. When the series was completed, each subject had been tested over three days on the control beverage and three days on each of the two experimental beverages.

Subjects were provided with measured quantities of one of three beverages. The control drink was a water placebo (WP) colored and flavored with citric acid and aspartame to the appearance and taste of the other beverages. One of the carbohydrate-electrolyte drinks was a commercially available 5% carbohydrate mixture containing citric acid, sucrose, fructose, and electrolytes (CE). The third beverage tested was a 4% carbohydrate mixture consisting of citric acid, sucrose, glucose, electrolytes, and pyruvate (CEG). The third drink, CEG, was mixed with 1% (by volume) glycerol. All beverages were blended to provide similar consistency, appearance, and taste. Color, flavor, and fluid composition were adjusted with inert ingredients to disguise differences in beverage composition. The electrolyte concentration of beverages CE and CEG were similar. All drinking fluids were maintained at normal ambient temperature (21-25 °C) for consumption. Neither subjects nor monitors were informed of the identity of the drink being used. The presentation of the drinks was randomized for each subject.

Each test cycle began at 0600 on day 1 and continued for 60 h through 2000 on day 3. This provided three day and two night cycles at desert temperatures for each subject. One-half hour for personal hygiene outside of the environmental chamber was allotted at 0600 and 2000 of each test day.

On the first day of the study, subjects received a breakfast of 178 ml of orange juice, 1 bagel with a teaspoon of margarine, 275 ml of cereal (Cheerios) with 118 ml of milk, and 1 banana. After the breakfast, all subsequent

meals were selected from standard field rations, U. S. military Meals Ready to Eat (MRE). The subjects were allowed to select their meals from a variety of available MREs. Each group of three subjects, however, had the same meals at each mealtime. The MREs were weighed before and after consumption, and the weight recorded. A complete detailed list of the nutritional composition of each MRE was maintained in the laboratory for reference. The caloric content of the meals ranged from 1230 to 1446 cal. The approximate composition of the MREs was 15% protein, 36% fat, and 49% carbohydrate.

One-half hour after completing breakfast, subjects were given 250 ml of the beverage, then entered the environmental chamber and assumed a resting, seated position for 1 h. Fluids were continuously available to subjects in the environmental chamber. Subjects were encouraged to drink *ad libitum* and to try to consume the equivalent of 1 liter (canteen) per hour. All fluid intake, urine output, sweat rates, and body weights were recorded.

The subjects were instrumented with three skin (thigh, chest, and arm) and rectal temperature sensors, ECG electrodes, and a hygrometer sensor on the lateral calf for sweat rate. The subjects then donned military clothing consisting of utility trousers, blouse, and boots. After the initial rest period in the environmental chamber, the temperature was raised to 35 °C, and the subjects, in turn, began the first of three daily exercise cycles. They walked on a motorized treadmill at 4.8 km/h (3 mph) and 0% grade for 40 min during daytime environmental temperatures of 35 and 45 °C (Figure 1). During the first and last 10 min of each trial, subjects were connected to a metabolic analyzer. Expired air was analyzed for oxygen consumption (VO_2) and carbon dioxide production (VCO_2), which was used to calculate the respiratory exchange ratio (RER). Heart rate (HR) and an electrocardiogram (ECG) were recorded continuously along with the metabolic data. Skin temperatures (Tsk) at three sites (thigh, arm, and chest) and core temperatures (Tre) were recorded continuously throughout the tests. Sweat rate (SR) was measured with a dewpoint hygrometer connected to a capsule attached to the calf of the subject. Sweat rate was determined by comparing the ambient dewpoint temperature to the dewpoint temperature obtained from air that had been drawn over the subjects' skin. Nude and fully clothed body weights were measured at 0600 and at 2000 in the environmental chamber. Changes in total body weight were used as an indicator of total net fluid loss. At the end of each exercise bout, subjects were asked to rate their overall body perceived exertion (RPE) using the Borg scale (24) shown in Figure 2.

During exercise, each subject carried a rifle, helmet, flack jacket, web belt and harness, and two full canteens (approximately 16.5 kg total additional weight). Total subject weight during exercise was approximately 18 kg above nude weight. The work sequence was randomized for the initial treadmill bout, then the order of exercise remained consistent for the remainder of that day for the three subjects in the chamber. Subsequent daily exercise sessions were adjusted to provide uniformity of work/rest cycles. Subjects relaxed and engaged in recreational activities but remained inside the chamber when not exercising. All subjects slept in the chamber with nighttime of 25-28 °C during each of the trials.

Data were analyzed by a two-way analysis of variance (ANOVA) with repeated measures. When significant F ratios were obtained, Tukey post hoc comparisons were used to determine specific differences. The level of statistical significance was accepted at $p < 0.05$. Data are presented as mean (standard error of the mean).

RESULTS

All of the subjects completed all of the exercise bouts except for one of the subjects who was unable to perform the third bout on day 1 of his CEG test due to nausea. The total amount of CE and CEG consumption was greater than WP ($p < 0.05$), but the amount of urine produced with WP was greater than with CE or CEG ($p < 0.05$). Body mass changes over the three days were more variable. With WP, six subjects lost weight, one subject gained weight, and two neither gained nor lost weight. For CE trials, four of the subjects gained weight, two lost weight, and three subjects ended at their starting weight. At the end of the CEG trials, five subjects had lost weight, two had gained weight, and two remained at their beginning weight. No significant differences in body weight occurred among beverage treatments.

Significantly greater ($p < 0.05$) sweating rates were noted for CEG when compared to the other two beverages for exercise periods one and two on days one, two, and three, and for exercise period three on days two and three (Table 1). The highest sweat rates occurred with CEG during all three days. Sweat rate appeared to increase from exercise period one to period two then decline during period three to levels below those of exercise one.

Table 1 shows that the thermoregulatory response as measured by peak Tre was significantly ($p < 0.05$) lower with CEG than WP for exercise period three on days one and three, significantly lower with CE than CEG during exercise three on day two, and significantly lower with WP than CE during exercise one on day two. All three beverage treatments were accompanied by similar Tre measurements during exercise period one on days one and three and exercise period two on days one, two, and three. The Tre response increased during exercise from day one to day two and either remained elevated or increased slightly higher again during day three. Skin temperatures (Table 1) averaged from the three body sites showed significant differences among all three drinks during exercise period two on days one and two and during exercise three on day two. All other skin temperatures among the three drinks were very similar.

The cardiovascular response exhibited a similar pattern among all drinks with peak HR during exercise decreasing each day for six of the bouts and increasing in only three sessions (Table 2). The daily HR response for each beverage was to increase from the first period to the second and then drop back to exercise period one HR levels during the third exercise bout. We found no statistically significant differences in HR among drinks, although the

trends by drink were higher HR for CE and CEG than WP on day one and two and greater for CEG compared to the other two drinks on day three.

Peak VO_2 measured during the last 10 min of each exercise bout was similar among exercise periods but showed a significant drink effect ($p < 0.05$) (Table 3). Oxygen consumption with CE was significantly higher than CEG or WP during the third exercise period on day one and higher than WP during exercise one on day two. Differences among all three drinks were seen during exercise period two on day three and during exercise period three on days two and three. CEG showed the lowest VO_2 during exercise two on the second day and during exercise one on the third day. RER (Table 3) was calculated from the oxygen consumption and carbon dioxide production during the last 10 min of exercise. RER was significantly lower ($p < 0.05$) for CEG than WP or CE during all three exercise periods on the first day only. Ratings of perceived exertion (Table 3) showed no significant difference among any of the beverages for any of the exercise periods or days.

DISCUSSION

Much of our understanding of how body water loss changes the regulation of body temperature during exercise in the heat has been derived from hypohydration experiments. These studies have demonstrated that a 3-7% reduction in body weight from fluid loss will elevate core temperature and HR during exercise (1,2), and that the increase in core temperature appears to be due to a delayed onset of sweating, and to reduced skin blood flow (25). These experiments (1,2,25) showed that the physiological mechanisms attenuating hyperthermia through fluid ingestion during prolonged exercise are not well understood.

The present study provided prolonged heat stress with moderate, intermittent, discrete exercise periods. Our subjects did not lose significant amounts of body weight from sweating without fluid replacement. Regardless of beverage, their physiological response did not represent an abnormal hyperthermic reaction indicative of hypohydration. Heart rate recorded during exercise was representative of submaximal work in the heat. Heart rate did not increase beyond submaximal levels suggesting that subjects were adequately hydrated and were not lacking in energy substrate. While high rates of fluid replacement have been shown to lessen hyperthermia and reduce heart rate during exercise in the heat, no attempt was made to hyperhydrate during the study, although subjects were encouraged to drink 250 ml every 15 min on the treadmill.

Current recommendations for fluid consumption depend on wet bulb globe temperatures, work intensity, clothing, and work/rest cycles (18). The maximum SR (approximately 2 l/h) is closely related to the maximum water requirement, but is higher than the rate of absorption from the gut (approximately 1.4 l/h). Total water consumption for a 12-h work day should be about 11-14 l when sweat rates are normal (1.0 to 1.5 l/h). Fluid consumption during our study was compatible with these requirements. Likewise, sweating rates and urine volume were not high enough over the duration of this study to require extreme fluid replacement. Daily differences in the amount of fluid ingested were not due to variations in flavoring or temperature among the drinks since all drinks were kept at the same approximate temperatures and were equivalent in color and consistency. This implies that the physiological differences were due to the constituents of the beverages and their effects on adequate hydration and blood substrate levels required for optimal work performance.

In our study, carbohydrate fluids were ingested throughout the 60-h experiment. Because the carbohydrate concentrations of the beverages were relatively low (5 and 4%), it is uncertain whether sufficient carbohydrates were consumed to enhance the work capacity, prolong endurance, and reduce fatigue. It is, however, interesting to note that the differences among work performance and temperature regulation measures did not indicate a clear advantage for carbohydrate drinks over the three days. It could be easily assumed that the cumulative effects of heat stress and exercise would become evident in reduced work performance and increased fatigue during the second and third days. Some of our findings are consistent with the theory that the carbohydrate solution with glycerol performed better in providing glucose and maintaining hydration during the latter stages of chronic heat exposure. The exercise response with CEG on the first day showed a significantly low RER signifying primarily fat metabolism for energy with a positive effect on work performance. After the first day, the exercise response with CEG hints at a positive effect on VO_2. Likewise, CE and CEG showed an inconsistent, but possibly beneficial effect on temperature regulation when compared to WP over the 60 h.

When glycerol is consumed, it is evenly distributed among all fluid compartments in 65% of the total body mass (5). The osmotic action of glycerol causes the water ingested with the glycerol to be easily distributed with the glycerol. Because glycerol is readily catabolized to carbon dioxide and water, the water that moved with the glycerol is readily available for maintaining blood volume. With the more hypertonic CEG drink, we observed an increase in SR. Our findings are similar to a previous report (5) that ingestion of glycerol augments fluid retention and results in increased SR and decreased urine output. The previous report also showed an alteration in the thermoregulatory set point (5). We could not conclude that CEG was associated with a consistent decrease in Tre since both Tsk and Tre were widely variable for CEG when compared to WP or CE over the three-day period. The temperature extremes and military clothing worn in our study made it difficult to determine any change in the sweat response at lower Tre sufficient to change the set point. We did not observe a consistent increase in Tre and decrease in Tsk with CEG that would have implied that the effects of serum hypertonicity reduced heat loss by increasing threshold temperatures for sweating and skin blood flow. We did not show an increased Tsk and decreased Tre, accompanied by increased SR, that would have suggested a lowered threshold temperature for sweating and skin blood flow, facilitating the thermoregulatory response.

Enhanced work output, as measured by VO_2, corresponds

well with RER values elevated following carbohydrate ingestion (16). In our study, consumption of CEG produced significantly lower VO_2 than WP or CE during exercise bouts two and three on day two, and during exercise one, two, and three on day three. Oxygen consumption measurements among beverages on day one were similar except that CE was higher than the other two during the third exercise period. The lower VO_2 with CEG indicates that the energy expenditure at equivalent workloads was reduced, delaying fatigue and enhancing performance during the late stages of exercise.

The subjective RPE scores were not congruent with the physiological work performance measurements. Perceived exertion was rated slightly higher, but not significantly, for all three beverages during the second exercise bout on all days. Subjects reported greater perceived exertion during the exercise periods that occurred during the hottest part of the day. All of the RPE measures were in the range of "light" to "somewhat hard."

In summary, the 60-h exposure to simulated desert conditions was well tolerated by all subjects. Nine submaximal exercise sessions in the heat were performed without adverse results. Carbohydrate-electrolyte-glycerol containing beverages seemed to offer some initial benefits in maintaining positive fluid balance during the first 24 h of heat exposure, but those benefits were less apparent over 60 h. By the third day of our study, water appeared to support the overall physiological response as well as either of the other beverages. We found no advantage to drinking either carbohydrate-electrolyte or carbohydrate-electrolyte-glycerol beverages over water during extended periods of time in the heat. It is important to consider these findings as representative of 5% carbohydrate and 4% carbohydrate-1% glycerol drinks during a 60-h time period in the heat. Carbohydrates in these concentrations may or may not have delayed fatigue and enhanced work performance. While these beverages did not appear to show a prolonged physiological benefit, neither did they demonstrate any negative effects during the same period. Based on these findings, we cannot recommend either CE or CEG as a performance aid during activities similar in duration to those in this study. We can suggest that these beverages may be beneficial during the initial phase of heat acclimatization and would welcome participation in field studies to corroborate these findings.

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Table 1. Sweat Rate (SR), Rectal Temperature (Tre), and Average Skin Temperature (Tsk) during the last 10 minutes of each exercise period each day for three beverages.

	Day 1			Day 2			Day 3		
Drink	EX1	EX2	EX3	EX1	EX2	EX3	EX1	EX2	EX3
SR (g/h)									
WP	30.9 (2.9)	37.0 (3.8)	36.4 (3.0)	32.8 (2.0)	36.9 (4.9)	27.7 (2.1)	29.3 (3.0)	37.1 (2.8)	27.4 (2.5)
CE	35.8 (3.1)	38.6 (3.8)	32.6 (5.0)	31.9 (2.5)	44.1 (4.2)	27.9 (3.9)	33.8 (4.0)	39.0 (2.6)	24.8 (2.5)
CEG	40.5 (3.6)	47.1 (3.1)	34.1 (2.5)	39.1 (4.9)	51.3 (4.1)	38.5 (4.4)	37.2 (3.6)	42.3 (3.2)	35.7 (4.1)
Tre (°C)									
WP	37.5 (0.4)	38.3 (0.2)	38.1 (0.2)	37.5 (0.4)	38.5 (0.1)	38.2 (0.1)	38.0 (0.1)	38.3 (0.3)	38.3 (0.2)
CE	37.8 (0.4)	38.1 (0.2)	37.8 (0.2)	38.1 (0.4)	38.3 (0.1)	37.9 (0.1)	38.0 (0.1)	38.2 (0.3)	38.0 (0.2)
CEG	37.6 (0.1)	38.1 (0.3)	37.5 (0.4)	37.9 (0.1)	38.4 (0.1)	38.4 (0.2)	37.9 (0.2)	38.4 (0.2)	37.7 (0.3)
Tsk (°C)									
WP	35.4 (1.6)	36.8 (1.6)	35.8 (1.7)	35.4 (2.0)	37.0 (2.0)	35.1 (2.1)	35.3 (2.4)	36.6 (2.1)	35.7 (2.0)
CE	35.1 (1.5)	35.9 (0.4)	35.4 (0.3)	35.4 (1.4)	35.4 (0.3)	36.3 (0.4)	35.5 (3.4)	36.0 (0.3)	35.9 (1.7)
CEG	35.4 (1.6)	37.1 (1.7)	35.7 (2.1)	35.4 (2.0)	35.9 (1.7)	36.4 (1.6)	35.4 (1.6)	37.1 (1.6)	35.8 (1.6)

Mean (SE)
WP = water placebo; CE = 5% carbohydrate drink;
CEG = 4% carbohydrate, 1% glycerol drink

Table 2. Heart rate (HR) during the last 10 minutes of each exercise period each day for three beverages.

	HR (beats/min)								
	Day 1			Day 2			Day 3		
Drink	EX1	EX2	EX3	EX1	EX2	EX3	EX1	EX2	EX3
WP	101 (5)	120 (7)	115 (5)	98 (7)	121 (5)	116 (5)	104 (7)	122 (7)	104 (7)
CE	108 (5)	134 (7)	115 (6)	102 (5)	131 (5)	108 (5)	113 (4)	121 (5)	97 (7)
CEG	119 (4)	134 (6)	121 (5)	116 (6)	126 (5)	116 (3)	110 (3)	132 (3)	106 (4)

Mean (SE)
WP = water placebo; CE = 5% carbohydrate drink;
CEG = 4% carbohydrate, 1% glycerol drink

Table 3. Oxygen consumption (VO_2), respiratory exchange ratio (RER), and rating of perceived exertion (RPE) during the last 10 minutes of each exercise period each day for three beverages.

	Day 1			Day 2			Day 3		
Drink	EX1	EX2	EX3	EX1	EX2	EX3	EX1	EX2	EX3
VO_2 (ml/min/kg)									
WP	15.7 (1.1)	15.0 (1.1)	15.4 (1.1)	14.4 (0.6)	15.5 (0.5)	15.2 (0.6)	15.9 (0.7)	15.7 (0.8)	15.3 (0.6)
CE	15.8 (0.5)	15.7 (0.8)	16.4 (1.0)	15.5 (0.6)	15.6 (0.4)	16.2 (0.5)	16.2 (0.6)	16.3 (0.8)	16.4 (1.1)
CEG	15.6 (1.0)	15.3 (1.0)	15.5 (1.2)	14.9 (0.6)	14.8 (0.7)	14.3 (0.5)	15.5 (0.9)	15.0 (0.6)	14.7 (0.5)
RER									
WP	0.84 (.02)	0.82 (.02)	0.78 (.02)	0.89 (.01)	0.88 (.01)	0.89 (.02)	0.87 (.02)	0.87 (.02)	0.86 (.02)
CE	0.81 (.02)	0.80 (.01)	0.83 (.02)	0.88 (.01)	0.88 (.02)	0.90 (.01)	0.86 (.02)	0.88 (.02)	0.88 (.01)
CEG	0.76 (.01)	0.76 (.01)	0.76 (.01)	0.88 (.01)	0.89 (.01)	0.90 (.01)	0.85 (.02)	0.88 (.01)	0.86 (.02)
RPE									
WP	11 (0.2)	13 (0.2)	12 (0.3)	11 (0.3)	13 (0.5)	12 (0.4)	12 (0.3)	14 (0.4)	12 (0.3)
CE	11 (0.4)	13 (0.5)	12 (0.3)	12 (0.3)	13 (0.5)	12 (0.2)	12 (0.2)	13 (0.6)	12 (0.2)
CEG	12 (0.4)	13 (0.5)	12 (0.3)	12 (0.3)	13 (0.4)	12 (0.5)	12 (0.2)	13 (0.3)	12 (0.5)

Mean (SE)
WP = water placebo; CE = 5% carbohydrate drink;
CEG = 4% carbohydrate, 1% glycerol drink

Figure 1. Temperature profile followed during the study with approximate periods of exercise indicated.

```
Temperature (°C)                 ___45°___
                                 /         \
                                /           \
                   ___35°___/               \___35°___
                  /                                    \
                 /                                      \
      ___25°___/                                        \___25°___

                  Exercise 1---Exercise 2---Exercise 3

Time  0700----------------------1200-----------------2000-----
```

Figure 2. Borg Scale of Rating of Perceived Exertion

6	NO EXERTION AT ALL
7	EXTREMELY LIGHT
8	
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD (HEAVY)
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

ALLEVIATION OF THERMAL STRAIN IN THE CF: "KEEPING OUR COOL" DURING THE GULF CONFLICT

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1. SUMMARY

Thermal stress can be a serious problem for military personnel. This is largely because the measures employed to reduce such stress under normal working conditions are impractical under operational circumstances. For example, the specialized clothing worn by soldiers cannot generally be removed to reduce insulation and facilitate cooling. Similarly, operations are often conducted in hostile environments where ambient conditions, even inside vehicles, cannot be altered substantially. While reductions in work rate are feasible during peacetime, they have little place in combat as they compromise objectives and may still not be adequate to reduce thermal strain to acceptable levels. When operationally feasible, the provision of personal cooling can assist the body with heat dissipation and thermoregulation, often to the point that work can be continued at a near-normal rate with only slight to moderate thermal strain.

This paper presents an overview of personal cooling technology studies conducted at DCIEM within the last decade. It outlines the problems of thermal stress in operations and its effects on performance, examines various solutions to the problem, and summarizes the R&D efforts that culminated in the integration of personal cooling into the CH124 Sea King helicopters during Op Friction. This was to our knowledge the world's first use of air crew personal cooling garments during combat and it enabled the Canadian Forces (CF) to conduct their Sea King helicopter operations without being time-limited due to thermal physiological strain.

2. WHY PERSONAL COOLING?

The sources of heat stress that the body must contend with can be classified into two broad categories. Internal heat is derived primarily from metabolism and the combustion of food. In addition to the heat arising from life-sustaining basal ($\approx$80 W) or resting metabolism ($\approx$100 W), exercise and external work can increase the internal heat production of the body several fold (heavy work will raise metabolic heat production to $\approx$500-800 W). Due to the $\approx$20-25% efficiency of muscular contraction, the internal heat production is some 4-5 times the amount of external work performed.

External sources of heat stress include the environment (ambient temperature, humidity, solar radiation, presence or absence of wind), vehicles (engines, instrumentation), and machinery. In the case of aircraft, aerodynamic heating of the aircraft body can be a significant source of heat stress, especially during low level flight where the air is more dense. Clear canopies and windows can also produce a greenhouse effect.

A constant body temperature can only be maintained if heat gain is balanced by heat loss. This process becomes increasingly difficult as the environment around the body becomes warmer. In fact, the common avenues of heat dissipation (conduction, convection, radiation) all become avenues of heat accumulation when the temperatures of the surroundings exceed skin temperature (under these conditions, evaporation of sweat is the only means left for dissipating body heat).

Most of the heat lost by the body passes through clothing to the environment (only a small amount is lost through breathing and from

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uncovered skin). The clothing is, in essence, a thermal resistance to the flow of heat. To make matters worse, military personnel are often required to wear specialized protective clothing which greatly increases the thermal resistance between the body and the environment. Such clothing also interferes with evaporative cooling of the body. Failure to dissipate adequate quantities of heat results in body heat storage and an increase in body temperature (thermal strain). Excessive thermal strain impairs mental performance and eventually leads to physiological incapacitation.

The typical approaches to reducing thermal stress are not always feasible during military operations. For example, removal of protective clothing to reduce insulation is certainly not possible during times of chemical threat. Reductions in metabolic rate are also not practical if objectives must be met within limited time frames (i.e., recommended work-rest schedules cannot be used). Finally, altering the external environmental conditions is simply impossible, and even macroclimate conditioning (i.e., air conditioning of vehicle interiors) is often ineffective due to the insulation of the protective clothing. In general terms, macroclimate conditioning can facilitate dissipation of heat, but the real problem is high internal heat production and its containment within the body by the insulation of operationally dictated clothing.

The notion that retention of metabolic heat in chemical defence (CD) clothing is a problem was clearly demonstrated in a study of thermal stress in CF188 aircraft conducted in Germany during the spring of 1988. Three pilots flew 3 missions per day for 2 consecutive days, followed by a single mission on the third day, while wearing the full complement of Individual Protective Equipment (IPE) (1, 2). Rear seat safety pilots wore standard flight clothing (i.e., NOIPE) and were treated as physiological controls. During the second week of the study, IPE and NOIPE pilot pairs reversed roles, yielding a total of 42 man-missions completed in full IPE. All pilots were instrumented with a rectal probe early in the morning, and rectal temperature (Tre) was monitored continuously throughout the day as the pilots went about their flying activities. Apart from the differences in flight ensembles and who was actually flying the aircraft, IPE and NOIPE pilot pairs performed virtually identical activities at the same time. Since IPE pilots remained dressed in IPE for the first 2 missions of the day but undressed and redressed for the evening flight, the daily temperature results are broken into 2 segments.

While the results in Figure 1 show that IPE pilots suffered significantly greater (although relatively mild) thermal strain than their NOIPE counterparts, they also show that Tre in both groups of pilots rose whenever physical activity increased (e.g., dressing, walking, climbing and strapping into the aircraft, flying) but fell whenever physical activity was reduced (e.g., doing mission planning, performance tests at a computer terminal, being driven to the hangar, resting between sorties). It was concluded that elevated metabolism coupled with the insulation of clothing led to increases in core temperature during times of physical exertion. The increases were significantly greater for the IPE pilots wearing more insulation. The recommendations from that study were to limit pilot physical activity by using a buddy system for dressing in IPE, driving air crew between bunkers and hangars in air conditioned vehicles, having ground crew or other personnel conduct aircraft walk-around inspections, assisting pilots with ingress/egress procedures, and providing a cool resting place for pilots between missions.

Microclimate conditioning can overcome some of the above difficulties by removing metabolic heat from the body before it has to pass through multiple layers of insulative clothing. In general, the closer the system gets to the skin the more effective it is, but it may then also require more careful control of temperature in order to maintain user comfort. In this regard, passive ice cooling systems may be less desirable than those based on liquid or air because they offer no means of controlling the rate or degree of cooling. A study of the Steele vest (an "ice" vest) conducted at DCIEM reported that the vest could not be worn next to the skin because of excessive initial cold discomfort; the vest was, therefore, worn over an undershirt (3). That same study found no significant increase in work tolerance time in the heat while wearing the ice vest, perhaps because of too much insulation between the ice and the body (the vest itself is made of heavy fabric).

Cooling garment efficiency should be enhanced by extra insulation between the cooling garment and the hot environment because less ambient heat would be absorbed by the garment. Studies of a Life Support Systems Inc. (LSSI) liquid cooled vest on a thermal manikin verified that this was indeed the case. Parallel studies with human subjects wearing the cooling vest in the heat showed that core temperature increases

were less when a heavier (CD) flight ensemble was worn compared with a standard (non-CD) flight ensemble (mean ΔTre of 0.4°C vs. 1.0°C, respectively). Body heat removals of ~70 W and cooling garment efficiencies of 50-80% were obtained with the standard flight ensemble (4). It should be pointed out that rather large variability in the heat removal and efficiency data was observed in this study. The LSSI vest can lose contact with the body when the cooling channels are pressurized by the circulation pump, and posture of the subject will greatly affect contact and the degree of heat transfer.

3. COOLING MEDIA

The majority of personal cooling garments use either water (with or without an antifreeze agent) or air as the cooling medium. Two notable exceptions are the Steele vest mentioned above which uses freezable blue gel packs, and the Thermacore vest which uses the direct evaporation of freon. All approaches can be effective if the system is well designed, and the final choice is often dictated by operational requirements and technical constraints. Table I lists some of the advantages and disadvantages of both air and liquid systems.

DCIEM developed an air vest because of its specific advantages over a liquid system when related to use in a high-performance aircraft already equipped with an on-board air conditioning system or environmental control unit (ECU) (e.g., CF188 Hornet). The design principle of the vest is the creation of a manifold that can distribute low pressure cooling air across the torso even under tight fitting clothing such as a positive pressure breathing jerkin. A spacer fabric sandwiched between two layers of air-impermeable fabric where the inner (body side) layer is perforated with 1/8 inch diameter holes forms the manifold. A second layer of spacer fabric interposed between the manifold and the body ensures that air leaving the manifold via the holes has an unimpeded path to flow across the body before escaping around the periphery of the vest.

Comparisons between the DCIEM air vest and the LSSI liquid cooled vest (5, 6) indicated better overall performance with the air vest. Objective data showed that rectal temperature increases were slightly less (by ~0.25°C) with the air vest compared with the liquid vest over 2.5 h of heat exposure at 37°C dry bulb temperature. This could have been due to the liquid vest losing contact with the body (as previously mentioned) whereas the air vest does not rely on such intimate contact for effective cooling. Undergarments were also much drier with the air vest (315 g of moisture gain with air vs. 668 g with liquid cooling), sweat rates were markedly reduced with air (0.49 kg/h) compared to liquid (0.62 kg/h), and subjects indicated they would choose the air vest over the liquid vest if given the choice.

4. BODY AREAS FOR COOLING

It is fairly straight forward from the principles of heat transfer that total heat removal can be increased either by increasing the surface area of coverage of the cooling garment or by decreasing the temperature of the working fluid (air or liquid). There is, of course, a limit as to how small an area can be used because it would require a very large temperature gradient and a high heat flux to achieve adequate cooling, and that could be very uncomfortable. On the other hand, cooling of the entire body with a small gradient may be impractical because of working fluid distribution difficulties in relation to other elements of clothing. For example, adding a cooling garment to the legs of a fighter pilot could cause discomfort during inflation of the G-suit, and kinks in the coupling tubes due to pressure or even posture could cut off fluid circulation to a portion of the garment completely. Clearly, a balance between temperature gradient and surface area covered should be sought, and this depends to some extent on the heat flux that can be drawn from specific body areas.

One body area that has been studied extensively is the head. There is evidence which shows that the head does not vasoconstrict excessively when exposed to cold. This is an advantage for cooling because high heat fluxes (~300 W/m^2; Frim, unpublished) can be obtained even with fairly cool fluids in a cooling cap. However, too cold a fluid can lead to discomfort, and total cooling capacity with head-only cooling is limited by the relatively small surface area involved. Surmised adverse effects of head cooling on thermoregulation because of cooling of the hypothalamus have never been substantiated.

If head cooling alone is not adequate for elimination of thermal strain, then one must increase the surface area being cooled. This then raises the question of whether one should still cool the head in addition to other body regions because in many circumstances cooling other parts of the body is simpler than cooling the head. In particular, high-performance aircraft pilots wear tight fitting helmets to reduce problems during high-G manoeuvres, and

provision of head cooling would require a second custom-fitted helmet, or at least a second liner, to accommodate the cooling cap. Coupling of cooling garment sub-elements (e.g., cooling cap to vest) can also complicate dressing procedures. If adequate cooling is available by other means, perhaps head cooling can be omitted.

A DCIEM study was conducted to evaluate the need for head cooling in addition to torso cooling (7). Six male subjects wore an LSSI liquid cooling vest and cap under standard CF summer flight clothing on three occasions in a climatic chamber at a dry bulb temperature of 42°C with a relative humidity of 50%. Radiant heat was added to the head to raise the globe temperature to 52°C at the head position. Cooling conditions were: CTRL, no fluid circulation; VEST, only torso cooling; and HEAD, both torso and head cooling. Cooling fluid was circulated at a flow rate of 0.3 L/min from a reservoir maintained at 10°C, which resulted in a garment inlet fluid temperature of 13°C. Subjects attempted to stay in the chamber for 180 min, doing a series of mental and motor performance tasks while seated in an aviator's chair.

The Tre data from this study are presented as a function of time in Figure 2. Most obvious is that fact that the chamber conditions were intolerable for more than ≈100 minutes with no cooling, whereas subjects were able to tolerate the full 180 minutes of heat exposure with body cooling. Although Tre was slightly higher when only the torso was being cooled compared to torso+head cooling, the difference was not statistically significant, and it was concluded that head cooling was not essential for reducing thermal strain in pilots. Subsequent studies with cooling vests (both air and liquid) confirmed that quantities of heat (≈160-180 W) sufficient to greatly reduce thermal strain could be removed with a vest-only system (6).

There is some interest in cooling other small regions of the body to effect whole body cooling. For example, Defence Research Establishment Ottawa (DREO) researchers have been examining hand and foot cooling and have found some success with this approach (8). However, the logistics of cooling body parts that are so highly mobile and where tactility and flexibility are important may make these approaches difficult to implement. It appears that there is again need for a balance between areas of high heat removal and the practicality of cooling that region of the body. The torso is perhaps the simplest body region to cool and it is not surprising that most cooling systems utilize at least a vest.

5. OP FRICTION

5.1 Background

On 10 August 1990 the Directorate of Maritime Aviation (DMA) advised DCIEM that on 24 August 1990 five Sea King helicopters and their crews would be deployed to the Persian Gulf for Operation Friction, part of Canada's participation in the United Nations activities against Iraq. Due to the high ambient temperatures in the Gulf region and the anticipated need for CD ensembles, DMA requested that DCIEM provide personal cooling systems for the air crew.

Despite years of research into personal cooling at DCIEM and development of both air and liquid garments, the CF had never brought a complete cooling system to operational readiness. One reason was that there had never before been a stated operational requirement; another was the lack of an aircraft compatible refrigeration system to provide the cold air or liquid. A serious attempt had been made to implement personal cooling in the Sea King helicopter using a DCIEM version of the LSSI liquid cooling vest and an Acurex Cooling Unit (a modified DC-10 ice maker) as the refrigeration unit (9). Field tests conducted from 1982-1986 with this and other refrigeration units showed the systems to be very unreliable and they were never recommended for implementation (10).

5.2 The Exotemp System

DCIEM was aware of other commercial developments in the personal cooling field. After considering the various options, a portable liquid cooling system made by Exotemp Ltd. of Pembroke, Ontario was selected as most suitable for the requirements of Op Friction. The system was originally developed for use with hazardous materials handling suits at Atomic Energy of Canada Ltd. as well as with explosive ordnance disposal suits.

The cooling garments consist of Nomex underwear to which PVC tubing (3/32 inch ID) has been attached on the inner side with overstitching. The garments include long johns, a long-sleeved turtleneck undershirt, and a cooling cap. Having demonstrated in previous work that torso cooling alone can substantially reduce thermal strain, and wishing to minimize modifications to CD clothing and procedures, it

was deci⁻ᵈed to use only the undershirt.

In the original version of the Exotemp system, ice water from a 2 L plastic reservoir is circulated through the garments by a battery operated pump. The reservoir, battery, and pump are all contained in an insulated nylon pouch with straps that allow it to be worn over the shoulder, around the waist, or strapped to a pant leg onto which a Velcro pad has been added. Again wishing to minimize extensive changes to the CD garments, the waist carrier option was selected as most suitable.

5.3 Physiological Evaluations

Due to the urgency of the situation, there was little time to conduct an extensive thermal physiological evaluation of the performance of the Exotemp cooling vest, yet it was deemed essential to have some idea of the performance of the system under the hot conditions expected in the Gulf. With only 1 cooling garment and 2 days of time available for testing, 4 subjects were tested only once, each wearing a different clothing configuration. To further save time, the protocol of an on-going air crew thermal stress study was adopted directly.

The tests were conducted in an environmental chamber set at a dry bulb temperature of 46°C and 30% relative humidity. Subjects entered the chamber and walked on a treadmill at 4 km/h for 10 minutes, and then sat down to rest for 20 minutes. Thereafter, each half hour consisted of 10 minutes of light arm exercise (arm curls with 1 kg weights at a rate of 1 up or down movement per second) followed by 20 minutes of rest, for a target exposure time of 150 minutes. Tests were conducted with both standard (STD) and CD flight ensembles, both with and without cooling. During non-cooled conditions the Exotemp undershirt was replaced by the standard air crew turtleneck underwear. If the exposure involved cooling, subjects were connected to the coolant supply after the 10 minute treadmill walk.

Figure 3 shows the changes in rectal temperature over time for each of the 4 subjects. Note that the subject in the CD-NoCool configuration terminated his exposure after only 70 min. This was due to personal time constraints and not to thermal stress. The data for that configuration have, however, been extrapolated with considerable confidence based on numerous past hot chamber studies (e.g., condition CTRL in Fig. 2). Whereas subjects in the non-cooled conditions showed core temperature increases that were rapidly approaching the allowable experimental tolerance limit of 2°C, subjects in the cooled conditions showed stable and only marginally elevated (<0.5°C) core temperatures. It is quite clear from these limited data that the Exotemp cooling garment did indeed reduce the severity of thermal stress on the body.

Figure 4 presents the skin temperature data from the CD-Cool test. The curve labeled "Periphery" represents the mean skin temperature of 7 body sites that were not under the cooling shirt, while curve "Torso" represents the mean of 5 skin temperature sites that were covered by the shirt. Note that the peripheral sites of the body were warmer than rectal temperature, indicating they were gaining heat from the environment and bringing it into the body. Heat flux measurements confirmed a heat gain of ≈40 W/m^2 at the periphery. In contrast, those sites that were under the cooling shirt were getting progressively cooler with time, thereby presenting the body with an internal (core-to-skin) temperature gradient for the dissipation of heat. Heat flux measurements on the torso indicated an average heat removal rate of just over 100 W/m^2.

The cycling of skin temperature on the torso deserves special attention. It does not represent any kind of physiological vasoconstriction or vasodilation response of the body; it is, rather, a purely physical phenomenon associated with periodic replenishment of the ice in the cooling reservoir. Under the chamber test conditions, the ice melted in 15-20 minutes and the cooling capacity was depleted in about 30 minutes. Part of the limitation in cooling capacity was the difficulty of packing the plastic reservoir bottle with sufficient ice chips. This was subsequently overcome by prefreezing the entire bottle to create a block of ice inside. Because of a fluid port near the bottom of the bottle, only about 1.5 L of water could be frozen, and the bottle had to be placed on an angle during freezing to prevent blockage of the port. However, this procedure approximately doubled the cooling capacity of the system, an important factor for the logistics of Op Friction. (Note that Exotemp has since then modified the coolant reservoir design so that fluid inlet and outlet are on the cap of the bottle. This permits the bottles to be frozen in an upright position with ≈1.9 L of water.)

5.4 Implementation

Having demonstrated that the Exotemp cooling undershirt could indeed reduce thermal strain, the system now had to be integrated into CH124

Sea King helicopter operations. That involved integration of the cooling undershirt with the CD ensemble, integration of the pump and cooling reservoir into the aircraft, and integration of the entire system into both aircraft and support ship operational procedures.

Most critical in clothing integration was finding a method of connecting the cooling shirt to the coolant supply while retaining the capability of donning and doffing the layers of the CD ensemble without cross contamination by liquid agent. The cooling garment also had to remain totally independent of the CD ensemble so that it could still be used with the standard flight clothing. The left side seam of the charcoal coverall was opened ≈4 inches at groin level where the delivery/return lines of the shirt were located. Mating swatches of Velcro were sewn into the opening so that the tubing from the shirt could be "clamped" into the gap. The CD coveralls were also opened on the left side and an "elephant trunk" or sheath of liquid-repellent fabric was sewn into the seam. Two short lengths of tubing were captively sewn into the sheath to effectively extend the cooling shirt tubing lines to the outside of the CD coverall. Connectors on the ends of the tubing were polarized male-to-female from body-to-cooling supply, but with the same polarity on any terminating pair of tubes. This greatly simplified dressing procedures since either extension tube in the CD sheath could be connected to either tube of the shirt (inlet/outlet of the shirt are interchangeable).

It was decided early on that the cooling reservoir/pump assemblies should be aircraft mounted rather than carried on the body. Criteria for mounting included proximity to the user, accessibility for in-flight replacement of ice bottles, access to pump speed controls, no permanent alterations to aircraft structure, crash worthiness, and ease of manufacture and installation of mounting hardware given the short time available. For each crew station, a "low-tech" solution using fabric pouches and straps, Velcro, or existing screws was used to mount the pump assembly on the seat or bulkhead. The mounting was firm enough so that during emergency egress from the aircraft the tubing and connectors would simply separate, leaving the pump assembly behind.

Although the original portable system was powered by 9.6 V-dc rechargeable batteries, Exotemp was able to provide 28 V-dc pumps for compatibility with aircraft power. An earlier decision to use battery power for the CD filter/blowers meant that wiring was already available at each crew station for powering the pumps. Extension tubes of 2-4 ft length between the man and the cooling reservoir completed the coolant flow loop.

The logistics problem of providing more than 30-40 minutes of cooling was solved by using picnic coolers to store prefrozen bottles of ice aboard the aircraft. Two coolers with a capacity of 10 bottles each were secured to a bulkhead in the aft cabin using webbing straps or bungee cord, and one of the crew had the responsibility of exchanging the bottles whenever they were depleted of cooling capacity.

The sailing from Halifax to Gibraltar was used to train air crew and ground crew in the use and routine maintenance of the cooling system, to conduct operational and technical evaluations of the system, and to develop solutions for any problems encountered.

5.5 System Performance

Twenty-three Op Friction air crew used the cooling system sometime during the trans-Atlantic training flights even though ambient conditions were generally not severe enough to necessitate its use (average temperature 25°C; maximum 32°C). During early trials the system frequently failed to provide cooling, due mainly to kinking of the supply/return lines under the clothing. Better attention to cooling line placement during dressing solved most of these difficulties. Since the Gulf war, steel coil springs have been placed over these coolant lines as stiffeners to prevent kinking.

From a thermal perspective, the system performed very well when it was functioning. During the trans-Atlantic trials, the pump was usually set to low speed since higher speeds produced slight cold discomfort. Most of this discomfort occurred immediately after bottle replacement, but the perception passed quickly as the body adjusted to the change. Sensations of "too cold" were reported only for about 14% of a mission duration. Air crew reported feeling "cool" or "medium" under the cooling garment, as well as "warm" or "medium" on the skin not under the cooling garment, about 40% of the time. However, they were "too hot" on uncooled body regions for about 25% of the time.

The overall performance of the cooling system was rated as good or excellent by all but one of the air crew (his complaint was related to kinking of tubing). Sixty-nine percent of air

crew indicated that their operational effectiveness was increased by the cooling system, while three air crew stated that their operational effectiveness was actually decreased. This rating was given because of the efforts expended to rectify tube kinking and inadvertent disconnect problems in-flight. Given that these minor technical difficulties have been solved with simple modifications, the system did receive a high success rating.

Perhaps the best testimonials to the benefits and success of air crew personal cooling were the inquiries from the British ship HMS Gloucester. They wanted to know how the Canadian pilots were able to fly 2-hour missions while their British counterparts were limited to 1-hour because of thermal stress.

A detailed report on the introduction of personal cooling for CH124 Sea King helicopters during Op Friction is available (11).

6. CONCLUSIONS

Personal cooling systems have been in development for many years and a variety of good components are available today. Such proliferation exists because specific applications impose unique constraints on the garment as well as on the coolant supply, and it is virtually impossible to design a universal cooling system that can be used under all circumstances. The aviation requirement is perhaps second only to manned space exploration in imposing severe weight and volume restrictions on equipment and systems. However, since personal cooling in aviation has never been deemed essential (as it is for space activities), its implementation has been greatly impeded. Despite the vast body of scientific evidence from laboratory studies and field trials that personal cooling can relieve thermal strain and enhance pilot performance, the push to "get on with it" has been lacking.

The Persian Gulf conflict provided that impetus to the CF when DCIEM was asked to provide personal cooling for the Sea King helicopter crew. Although no suitable system specific to that requirement had been developed, an existing system was quickly modified to fill the need. Paramount in achieving our objective in such a short time was the use of a "low-tech" approach to providing a coolant supply. The decision to use pouches, straps, Velcro, prefrozen ice bottles, picnic coolers and bungee cord, rather than wait for development of an aircraft-compatible refrigeration unit, allowed air crew personal cooling to be implemented quickly and tested in actual combat for the first time. The success of the system was clearly demonstrated by the interest of other nations in the Canadian equipment.

Perhaps it is time that personal cooling is deemed essential and that it becomes an integral component of future air crew life support systems.

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Table I. Comparison of Air vs. Liquid Cooling Garments

AIR:	Advantages - more natural cooling - light weight garment - no liquid spill hazard - simpler logistics (no antifreeze) - comfortable - no need for refrigeration unit in vehicle with ECU - auto-regulation of cooling via sweating control - undergarments stay drier - contact with body not essential	Disadvantages - require filtered air (filter size?) - larger CD suit penetrator - larger connectors - portability difficult - thick umbilical to air supply - difficult distribution over body with tight clothing - require vents if outer clothing is impermeable
LIQUID:	Advantages - portability with ice pack - simpler CD Ops procedures - small umbilical to fluid supply - easily controlled cooling - simple distribution over body - closed loop; no venting	Disadvantages - short duration of ice pack - may need butyl tubing for CD use

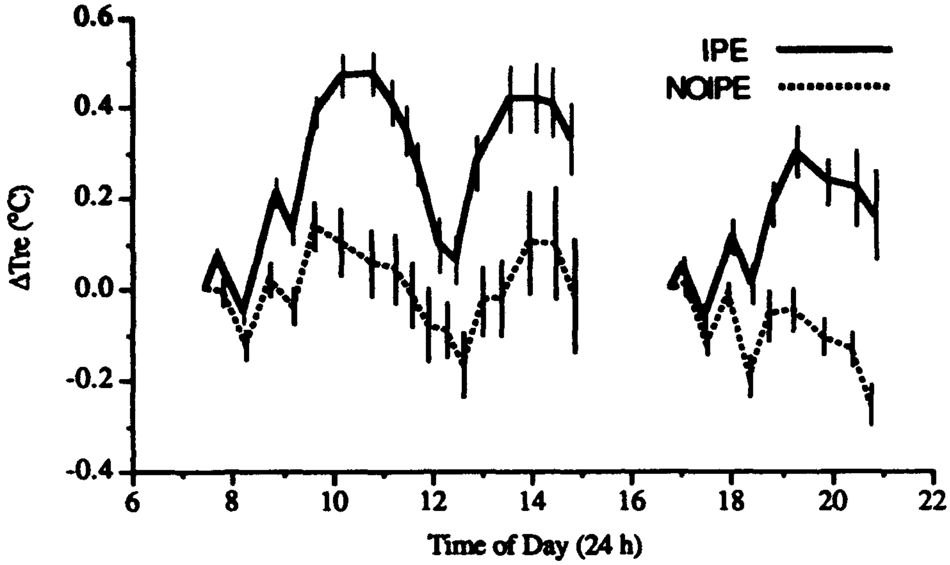

Figure 1. Change in rectal temperature (ΔTre) as a function of time of day for IPE and NOIPE pilots (see text). Values are means ± SEM for 6 subjects over 3 days. Flights took place between approximately 0940 - 1110 h; 1255 - 1425 h; and 1855 - 2025 h. Core temperatures increased whenever pilots were physically active and decreased when activity was reduced (see text). Although thermal physiological strain was not excessive in this study, it was significantly greater in IPE pilots compared to NOIPE pilots.

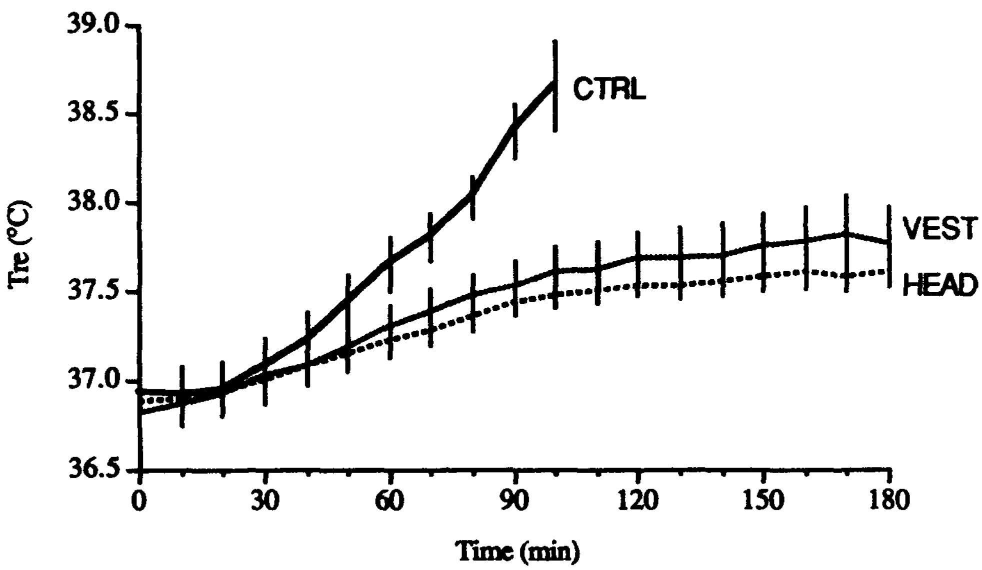

Figure 2. Rectal temperature (Tre) as a function of time for the 3 test conditions: CTRL, no cooling; VEST, torso only cooling; HEAD, torso + head cooling. Data are means ± SEM for 6 subjects. There were no significant differences between conditions HEAD and VEST (error bars are overlapped).

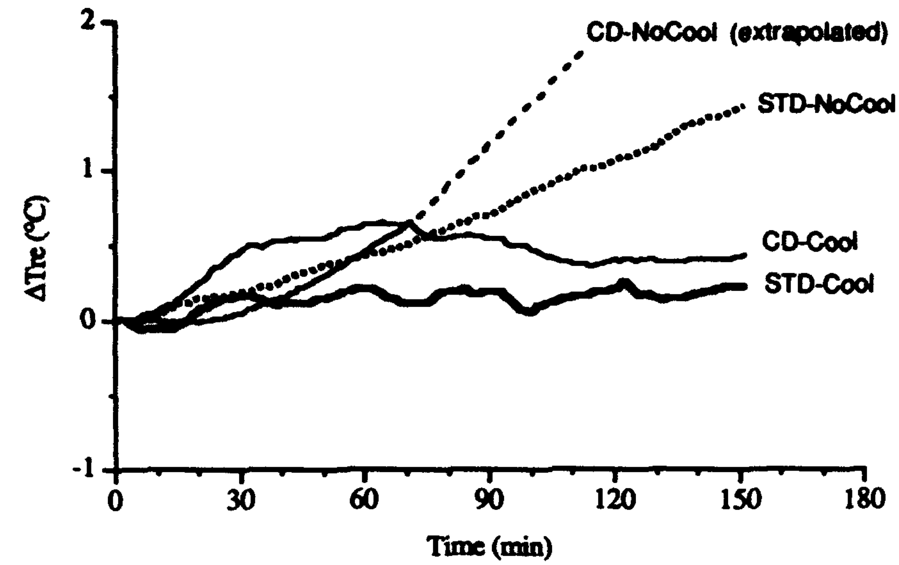

Figure 3. Change in rectal temperature (ΔTre) as a function of time in standard (STD) and chemical defence (CD) clothing, both with (Cool) and without (NoCool) cooling. Data are from individual subjects, and the CD-NoCool data are extrapolated after 70 minutes (see text). There is a clear reduction in thermal strain using the Exotemp cooling undershirt under these conditions.

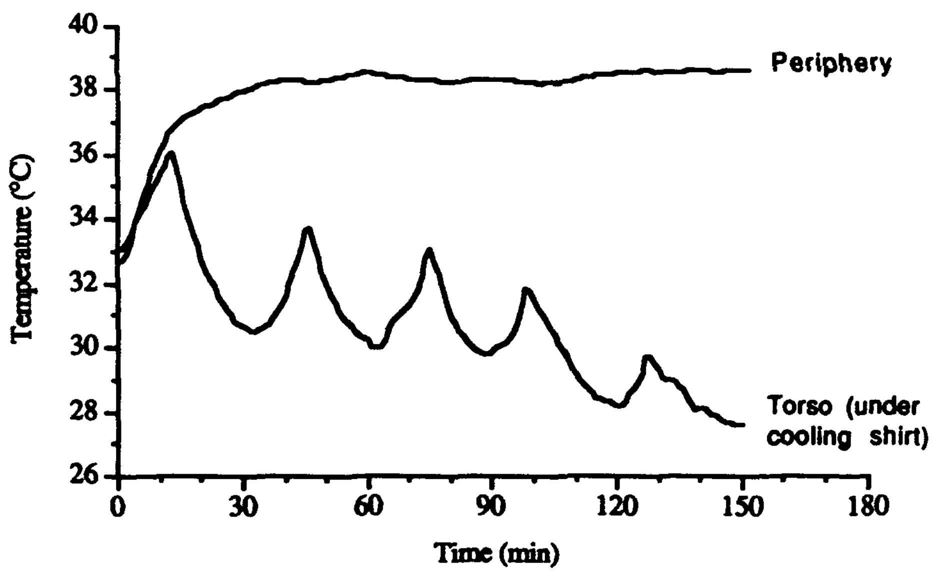

Figure 4. Skin temperatures as a function of time while wearing the CD flight ensemble and the Exotemp cooling shirt. "Periphery" shows the mean skin temperature of 7 body sites not being cooled, while "Torso" shows the mean temperature of 5 sites under the cooling garment. Cooling was only initiated after ≈10-12 minutes in the chamber. The cycling of temperature on the torso coincides with replenishment of the ice in the fluid reservoir.

EVALUATION EXPERIMENTALE DE DEUX SYSTEMES DE CLIMATISATION INDIVIDUELLE

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RESUME : La contrainte thermique en aéronautique militaire peut entraîner une baisse des performances physiques et psychomotrices; en particulier la tolérance aux accélérations est diminuée. L'utilisation d'un système de climatisation individuelle est susceptible de diminuer le stockage de chaleur et de permettre ainsi la prolongation des missions. Deux techniques sont envisageables: une circulation de liquide réfrigéré au contact du corps ou une ventilation d'air réfrigéré à l'intérieur de la combinaison. Deux systèmes ont été testés, utilisant l'un une circulation d'eau réfrigérée, l'autre une circulation d'air à 20°C saturé en vapeur d'eau. Le fluide, air ou eau, circulant au contact du corps est réfrigéré à l'aide de modules thermo-électriques. Les essais réalisés, sur sujets humains volontaires, en ambiance chaude allant de 40 à 50°C, ont permis de mettre en évidence une nette amélioration du confort thermique. Chacun des systèmes présente des avantages et des inconvénients. Ils doivent subir des améliorations technologiques afin de permettre leur utilisation à bord des avions de combat.

1 - INTRODUCTION

En milieu militaire, de nombreuses conditions opérationnelles exposent les personnels à une contrainte thermique importante. C'est le cas en particulier des chars (8), des hélicoptères (2-4) et également des avions de chasse (7, 13, 16). Dans ces deux derniers cas la contrainte résulte d'une charge thermique essentiellement externe.

En aéronautique, la charge thermique externe est le résultat de plusieurs facteurs. Par temps chaud, les conditons ambiantes régnant à l'extérieur de l'aéronef sont aggravées par l'échauffement aérodynamique de la structure lors des vols à grande vitesse et basse altitude. De plus l'importance des surfaces vitrées entraîne un effet de serre. Enfin le rayonnement de l'électronique de bord augmente la température ambiante. L'influence de ces facteurs est majorée par le port d'équipements spéciaux, particulièrement les équipements de protection physiologique contre les effets des accélérations et les équipements NBC (1, 9, 10). Tous ces facteurs concourent à une augmentation de la contrainte thermique entraînant une baisse des performances psychomotrices et une diminution de la tolérance aux accélérations + Gz (12).

Le récent conflit du Golfe Persique a démontré la nécessité de protéger les personnels navigants contre l'agression thermique chaude dans le but non seulement d'améliorer le confort, mais surtout de conserver les performances opérationnelles.

Deux solutions sont envisageables, soit une amélioration de la climatisation des aéronefs, soit l'utilisation d'une climatisation individuelle. La première solution apparaît coûteuse tant sur le plan financier que sur le plan de l'encombrement. De plus cette technique ne semble pas envisageable pour les avions actuellement en service. Enfin, lors de l'utilisation de tenues de protection NBC, la diminution de la température ambiante n'est pas suffisante, puisque ces équipements empêchent d'éliminer la charge thermique interne.

Ces remarques imposent donc l'utilisation, à bord des aéronefs, d'un système de climatisation individuelle. Cette technique permet à la fois de limiter les apports

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thermiques provenant de l'ambiance et d'éliminer la charge thermique de l'organisme.
De nombreux travaux ont porté sur des équipements de climatisation individuelle utilisant soit l'air, soit un liquide réfrigéré, soit de la glace (2, 6, 14, 16).
Le présent travail rapporte les résultats obtenus au cours d'expérimentations menées sur deux systèmes réfrigérants, l'un à circulation de liquide, l'autre à circulation d'air, destinés à être embarqués à bord des aéronefs.

2 - MATERIEL ET METHODES

2.1 - Systèmes de climatisation

2.1.1 - Système à circulation de liquide

Le système à circulation de liquide comprend un gilet, un système de réfrigération et un ensemble de connexion entre ces deux éléments. Le gilet se compose d'une enveloppe externe comportant une face aluminisée destinée à limiter l'apport calorique provenant de l'ambiance et d'une vessie en nylon. Celle-ci assure la distribution du liquide, ici de l'eau, au contact du corps grâce à un réseau de circulation en séries parallèle représentant un volume de 1,1 dm^3 environ.

Le système de réfrigération est composé d'un climatiseur à modules thermo-électriques qui assure le refroidissement de l'eau après son passage dans le gilet et d'un boîtier de commande. Celui-ci comprend une pompe assurant un débit d'eau de 0,9 $dm^3.min^{-1}$ et un potientiomètre qui permet de faire varier la puissance de refroidissement de 125 à 250 W.
Les connexions entre le module de refroidissement et le gilet s'effectuent grâce à des tubes en polyvinyle munis de raccords auto-obturables.

2.1.2 - Système à circulation d'air

La volonté d'embarquer à bord des aéronefs un tel système entraîne des impératifs de poids et de volume. Compte tenu de ces contraintes, le système assure uniquement la réfrigération de l'air sans l'assècher. Il comprend un climatiseur et un harnais de ventilation. Le climatiseur prélève l'air ambiant, le refroidit et l'envoie dans le harnais de ventilation. Il se compose d'une turbine et d'un échangeur constitué de deux modules à effet thermo-électrique, placés en série, d'une puissance maximale de refroidissement de 150 W chacun. Un boîtier de commande permet de faire varier cette puissance. Après refroidissement, l'excès d'eau peut être éliminé grâce à un séparateur d'eau centrifuge. L'ensemble assure un débit de 200 $dm^3.min^{-1}$ d'air refroidi à 20°C et saturé en vapeur d'eau.
Le harnais de ventilation est réalisé en GORETEX. Un système de distribution d'air est fixé à l'intérieur. L'air arrive dans une poche ventrale, puis est distribué dans des tubulures l'amenant vers les bras, les cuisses ainsi que vers une poche dorsale. La perforation des différents éléments permet d'assurer une distribution homogène de l'air sur tout le réseau.

2.2 - Sujets

Les essais avec le système à circulation de liquide ont été réalisés uniquement sur deux sujets masculins volontaires.
Les essais avec l'équipement ventilé ont été réalisés sur cinq sujets masculins volontaires. Ils étaient agés de 28 à 38 ans et leurs caractéristiques étaient les suivantes (moyenne ± SD): taille 176 ± 3 cm et poids 72 ± 4,7 kg.
Tous les sujets avaient bénéficié d'un examen médical, avant leur inclusion dans l'essai. Ils avaient été informés des buts et des moyens de l'expérimentation et qu'ils pouvaient à tout moment en interrompre le déroulement. A l'issue de cette information ils avaient donné leur consentement écrit.

2.3 - Protocole expérimental

Lors de l'expérimentation avec climatisation liquide, les sujets arrivent une heure avant le début de l'expérimentation. Ils s'équipent d'une sonde à thermocouple placée à 10 cm de la marge anale pour la mesure de la température rectale (Tre). Ils enfilent alors une combinaison munie de 10 thermocouples pour la mesure des températures cutanées. Ils revêtent ensuite des sous-vêtements et une combinaison de vol. Le gilet réfrigérant est placé au dessus de la combinaison. Les sujets pénètrent ensuite

dans la chambre climatique dont la température est régulée soit à 40°C soit à 50°C de Tg et 30 % d'humidité relative (HR). Les sujets sont alors connectés au module de réfrigération. La température de l'eau est mesurée à l'entrée et à la sortie du gilet. Les mesures physiologiques et physiques sont enregistrées toutes les minutes à l'aide d'un micro ordinateur.
A partir des températures cutanées individuelles, la température cutanée moyenne (Tsk) est calculée en utilisant les coefficients de pondération de HARDY.
Le stockage de chaleur est obtenu à partir du calcul de la température corporelle moyenne, Tb, somme pondérée de Tre et Tsk sous la forme :Tb = a Tre + b Tsk, avec à la neutralité thermique a = 0,73 et b = 0,27 et au chaud a = 0,8 et b = 0,2.

Lors de l'expérimentation avec ventilation, les sujets arrivent au laboratoire une heure avant le début de l'expérimentation. Ils sont pesés nus puis s'équipent des thermocouples pour la mesure des températures rectale et cutanées. Les sujets enfilent ensuite le harnais de ventilation puis une combinaison NBC destinée au PN. L'isolement de cette combinaison est de 1 clo. Le sujet est repesé habillé puis mis au repos pendant environ une heure dans une ambiance de 20° ± 1°C. Il pénètre alors dans le caisson climatique dont l'ambiance est régulée à 45°C et 25 % d'HR. Après vérification du bon fonctionnement des capteurs, le sujet est connecté au climatiseur qui est mis en route à puisssance constante de 250 W avec un débit d'air de 200 $dm^3 \cdot min^{-1}$, à la température de 20°C et saturé en vapeur d'eau. Le sujet reste assis pendant une heure sanglé sur un siège d'hélicoptère. A l'issue de l'essai, le sujet est repesé tout habillé puis nu, après déséquipement.
Pour chacun des deux systèmes réfrigérants, une expérimentation de référence, sans climatisation, a été réalisée dans les mêmes conditions expérimentales.

3 - RESULTATS

3.1 - Expérimentation climatisation liquide

Les résultats figurent dans le tableau n° 1

3.1.1. - Températures cutanées

Lors des essais à 40°C, la température cutanée moyenne est abaissée de 0,5°C par l'utilisation d'une climatisation individuelle (35,8°C avec gilet *vs* 36,3°C sans gilet). Cependant cette valeur moyenne masque une grande disparité. En effet, quand le sujet bénéficie d'une climatisation individuelle la température cutanée moyenne sous le gilet est diminuée de plus de 3°C (33,4°C *vs* 36,5°C) alors que la température cutanée du reste du corps est augmentée (37,3°C *vs* 36,2°C).
A 50°C les mêmes constatations peuvent être faites. Globalement la température cutanée moyenne est abaissée de 0,9°C avec le gilet (36,4°C *vs* 37,3°C). La température cutanée moyenne sous le gilet est inférieure de 4°C (33,7°C *vs* 37,7°C) alors que sur le reste du corps la température cutanée est supérieure de 1°C dans cette configuration (38,2°C *vs* 37,1°C).

3.1.2 - Température rectale

L'utilisation d'un système de climatisation individuelle limite de façon évidente l'élévation de température rectale liée à la contrainte thermique. En effet, à 40°C, la température rectale augmente de 0,7°C après une heure d'exposition sans protection alors qu'avec une climatisation individuelle l'augmentation n'est que de 0,2°C.
A 50°C l'exposition à la chaleur provoque une élévation de la température rectale de 1,1°C alors que l'utilisation du gilet de refroidissement limite cette élévation à 0,4°C.

3.1.3 - Stockage de chaleur

Quelles que soient les conditions ambiantes, le stockage de chaleur est diminué par l'utilisation d'une climatisation individuelle. Cette diminution atteint 34 % (105 kJ/m2 *vs* 159 kJ/m2) et 40 % (130kJ/m2 *vs* 226kJ/m2) respectivement à 40 et 50°C.

3.2 - Expérimentation climatisation par air

Les résultats figurent dans le tableau n°2.

3.2.1 - Températures cutanées

Les températures cutanées moyennes au début de l'expérimentation ne sont pas statistiquement différentes avec ou sans harnais de ventilation. En revanche à l'issue d'une exposition d'une heure au chaud avec ventilation, la température cutanée moyenne est significativement plus basse qu'à la fin du test de référence (34,22 ± 0,18°C *vs* 36,96 ± 0,18°C). Cette diminution est liée à une température cutanée basse au niveau du buste, seule zone ventilée (31,22 ± 0,8°C). Par contre en absence de climatisation individuelle, la température du buste est élevée et proche de la température cutanée moyenne (37,18 ± 0,13°C *vs* 36,96 ± 0,18°C).

3.2.2 - Température rectale

La valeur de la température rectale n'est pas modifiée par l'utilisation d'une climatisation individuelle par circulation d'air. On constate en effet qu'au début des essais la moyenne des températures rectales est de 37,12 ± 0,27°C sans protection, et de 37,16 ± 0,15°C avec protection (NS). A la fin d'une heure d'exposition à 45°C, 25 % d'humidité relative, ces températures sont respectivement de 37,4 ± 0,14°C et 37,42 ± 0,19°C.

3.2.3 - Stockage de chaleur

Le stockage de chaleur à l'issue de l'expérimentation de référence est de 172 ± 9 $kJ.m^{-2}$ alors qu'il n'est que de 90 ± 8 $kJ.m^{-2}$ avec climatisation individuelle. La réduction de la contrainte thermique est de près de 50 % et la différence est statistiquement significative ($p < 0,05$).

3.2.4. - Perte de poids sudorale

Les variations de poids entre le début et la fin de l'exposition à la chaleur sont différentes avec et sans ventilation (268 ± 54 g *vs* 338 ± 69 g). Cette différence n'est pas statistiquement significative. Les quantités de sueur évaporée sont du même ordre avec et sans ventilation (124 ± 38 g *vs* 168 ± 78 g $p > 0,05$). Le pourcentage de sueur évaporée est d'environ 50 % quelle que soit la situation expérimentale.

4 - DISCUSSION

En aéronautique militaire, les vols réalisés à basse altitude et grande vitesse ainsi que le port d'équipements spéciaux de protection anti-G et NBC augmentent de manière importante la contrainte thermique. Il devient indispensable d'utiliser des équipements de climatisation individuelle. Au cours de ce travail, nous avons testé successivement un système de circulation de liquide et un système ventilé.

La compatibilité de tels systèmes avec des avions de chasse repose sur leur autonomie et un faible devis de volume et de masse. En ce qui concerne les systèmes de climatisation individuelle que nous avons testés, qu'il s'agisse d'une climatisation par air ou d'une climatisation à circulation de liquide, nous avons choisi un système réfrigérant à modules thermo-électriques. Celui-ci peut être alimenté à partir du réseau électrique de bord. A notre connaissance, à l'heure actuelle, peu de systèmes déjà utilisés sont capables d'assurer une climatisation efficace pendant une durée quasi illimitée. Cadarette et coll (6) en 1990, testant trois systèmes différents du commerce, rapportent que le temps de fonctionnement est compris entre 20 minutes et 2 heures. Le système que nous avons utilisé offre une autonomie très nettement supérieure.

Lors des essais avec le système à circulation de liquide, nous avons délibérément choisi un équipement se portant au-dessus de la combinaison de vol. En effet, lors de la première définition, cet équipement devait être optionnel en utilisation opérationnelle, selon les conditions de vol. L'utilisation d'un sous-vêtement réfrigérant impose le franchissement des couches externes de combinaison, ce qui peut poser des problèmes techniques en cas d'utilisation d'une combinaison NBC. Cependant le port au dessus d'une tenue limite l'efficacité du système dont le principe est d'augmenter les pertes thermiques par conduction (5). Ceci est bien démontré par les résultats de l'expérimentation. En effet lorsque le système fonctionne à 40°C, il entraîne une diminution du stockage de chaleur de 54 $kJ.m^{-2}$, soit approximativement 30 W. A

partir des températures d'eau à l'entrée et à la sortie du gilet, on peut calculer la puissance effectivement absorbée par l'équipement. On obtient alors une valeur de 119 W. Le rendement du système est donc de 25% lorsqu'il est porté au dessus de la combinaison de vol. On peut rapprocher ces résultats de ceux publiés par Richardson et col. (5) qui dans les mêmes conditions expérimentales, 40°C avec utilisation d'un système à circulation de liquide obtenaient des puissances absorbées de 150W. Il faut donc conclure qu'avec le système testé la plus grande partie de la chaleur absorbée par le gilet provient de l'ambiance, ce qui n'est évidemment pas le but recherché. Des conclusions similaires peuvent être obtenues en partant des résultats des expérimentations réalisées à 50°C. La solution adoptée lors de ces essais apparaît donc insuffisante pour assurer le confort thermique du sujet. Cependant, si l'on prend en compte la valeur du stockage thermique à l'issue de l'expérimentation, on peut constater qu'il existe une amélioration des temps de tolérance. En prenant comme stockage maximum admissible une valeur de 210 $kJ.m^{-2}$ (3) on constate qu'à 40°C la limite de tolérance passe de 2h 20 min à 4 heures et à 50°C de 55 min à 2 h 20 min. L'adjonction d'un système de climatisation liquide permet donc à un sujet de supporter une température de 50 °C aussi longtemps qu'une température de 40°C sans protection. L'examen de nos résultats et la comparaison avec les données de la littérature permettent de penser que l'utilisation d'un tel système au contact immédiat de la peau et l'augmentation de la surface refroidie seraient susceptibles de maintenir le confort thermique. Cette hypothèse peut s'appuyer sur le fait que la température cutanée des zones refroidies reste dans les limites du confort thermique, et que par ailleurs l'augmentation de la température rectale reste faible au cours de l'exposition. De telles modifications sont à l'heure actuelle à l'étude et devraient permettre d'obtenir un ensemble de climatisation individuel satisfaisant.

En ce qui concerne le système réfrigérant par air, le choix des modalités de refroidissement a été dicté par un certain nombre de contraintes techniques. Les impératifs de poids et de volume imposés par l'installation à bord d'un aéronef ne permettaient pas d'opter pour une climatisation complète de l'air, avec réfrigération et assèchement, ce dernier étant coûteux en énergie et nécessitant un volume important. Le choix retenu a été celui d'une climatisation partielle, permettant de refroidir à 20°C sans l'assécher l'air prélevé dans l'ambiance. Les conditions expérimentales (45°C et 25% HR) étaient celles rencontrées dans les théâtres d'opération les plus fréquents des forces aériennes françaises. Sur le plan de la puissance absorbée par l'équipement, un calcul théorique a permis d'évaluer les pertes maximales attendues par convection et évaporation. En effet, en accord avec les données de la littérature (11,14), on peut estimer que, compte tenu du débit et des caractéristiques physiques de l'air, 246 W peuvent être en théorie éliminés par le harnais de ventilation (63 W par conduction et 183 W par évaporation). L'observation des résultats montre que s'il existe une diminution significative de la température cutanée des zones refroidies, en revanche, la sudation n'est pas modifiée significativement. Les études réalisées par Vallerand et col. (18) sur un système comparable utilisant un débit d'air de 280 $dm^3 \cdot min^{-1}$, à 13°C et 70% d'HR, ont montré que, dans ces conditions expérimentales, l'évaporation de la sudation avait un rôle prédominant sur la diminution de la contrainte thermique. Il est évident qu'un assèchement même partiel de l'air présente l'avantage de favoriser les pertes thermiques par évaporation et qu'un système utilisant de l'air saturé en vapeur d'eau à 20°C présente une efficacité assez faible sur ce type d'échanges.
D'autre part, le système utilisé possède des performances assez faibles au regard des techniques préconisées par ailleurs. Des études antérieures (résultats non publiés par Colin et Timbal), utilisant de l'air réfrigéré à des températures inférieures à 20°C et asséché, avaient démontré que dans une ambiance à 50°C, un débit d'air de 500 à 600 $dm^3 \cdot min^{-1}$ était nécessaire au maintien du confort thermique.

Les deux expérimentations présentées, climatisation par air ou par liquide, ont été menées à deux périodes éloignées dans des conditions expérimentales différentes. Il est donc difficile de comparer les résultats

obtenus. On constate cependant que ces deux systèmes sont susceptibles de diminuer de manière significative la contrainte thermique en ambiance chaude. Les tests de référence réalisés dans l'une et l'autre expérience confirment, s'il en était besoin, la nécessité d'une limitation de la contrainte thermique. Tous ces résultats sont cohérents avec ceux de la littérature, particulièrement lors du port d'une combinaison NBC (8).

Les résultats obtenus sur des systèmes embarquables, même s'ils ne sont pas totalement satisfaisants, démontrent la faisabilité d'une telle solution. Le choix entre climatisation liquide ou par air reste à faire. Les systèmes passifs utilisant de la glace ou du dichlorotétrafluoroethane (3,13) doivent d'emblée être éliminés, compte tenu du poids surajouté et de la gêne à l'éjection qu'ils peuvent entraîner. Les systèmes autonomes, thermo-électriques ou autres, qui assurent un fonctionnement illimité, doivent permettre de pallier de tels inconvénients au prix de l'utilisation de connecteurs auto-arrachables. La circulation par air semble en premier examen plus séduisante que la circulation de liquide du fait de son faible poids et de sa faible maintenance. Cependant, en condition NBC, le risque de contamination par l'air de climatisation n'est pas exclu et ce dernier point serait en faveur de l'utilisation d'une circulation de liquide. Il semble en effet techniquement difficile de filtrer d'importants débits d'air uniquement pour la climatisation du ou des pilotes.

L'efficacité des deux techniques apparaît comparable même si la ventilation semble posséder un léger avantage. Elle permet en effet de réduire la sudation et apporte un confort subjectif supérieur (18).

Dans l'avenir, des modifications seront entreprises sur les systèmes à circulation de liquide utilisant des modules thermo-électriques. La surface refroidie sera augmentée et l'équipement sera porté au contact de la peau. De telles améliorations doivent permettre d'obtenir des résultats comparables à ceux rapportés dans la littérature.

5 - CONCLUSION

Les expérimentations menées sur sujets humains volontaires ont permis de mettre en évidence l'efficacité d'équipements individuels de climatisation. Ils permettent de réduire la contrainte thermique en ambiance chaude, même en cas de port d'une combinaison NBC. L'utilisation de modules thermo-électriques permet d'envisager une autonomie illimitée pour un équipement embarqué à bord d'un aéronef de chasse. Des améliorations techniques restent encore à réaliser afin de pouvoir envisager une utilisation opérationnelle.

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TABLEAU N° 1

ESSAIS DU GILET A CIRCULATION D'EAU

Tg	Conditions expérimentales	Tsi	Tsf	Ts gilet	Ts rc	Trei	Tref	Tbi	Tbf	S
40	Sans gilet	34.5	36.3	36.5	36.2	37.4	38.1	36.53	37.74	159
	Avec gilet	34.2	35.8	33.4	37.3	37.3	37.5	36.37	37.16	106
50	Sans gilet	35.1	37.3	37.7	37.1	36.9	38	36.36	37.86	226
	Avec gilet	34.3	36.4	33.7	38.2	37.2	37.6	36.33	37.36	139

Tg: Température globe (°C)
Tsi: Température cutanée moyenne initiale (°C)
Tsf: Température cutanée moyenne finale (°C)
Ts gilet : Température cutanée moyenne sous le gilet (°C)
Ts rc : Température cutanée moyenne du reste du corps (°C)
Trei: Température rectale initiale (°C)
Tref : Température rectale finale (°C)
Tbi: Température moyenne du corps initiale (°C)
Tbi: Température moyenne du corps finale (°C)
S: Stockage de chaleur (kJ/m2)

TABLEAU N° 2

ESSAIS DE L'EQUIPEMENT VENTILE

Conditions expérimentales	Tsi	Tsf	Tbuste f	Trei	Tref	S	P1	P2
Sans équipement	33.1	37	37.2	37.1	37.4	172	338	168
Avec équipement	33.2	34.2	31.2	37.2	37.4	90	268	124

Tsi: Température cutanée moyenne initiale (°C)
Tsf: Température cutanée moyenne finale (°C)
Tbuste f : Température moyenne finale du buste (°C)
Trei: Température rectale initiale (°C)
Tref: Température rectale finale (°C)
S: Stockage de chaleur (kJ/m2)
P1: Perte de poids du sujet nu (g)
P2: Perte de poids du sujet équipé (g)

RECENT CANADIAN ADVANCES IN ACTIVE THERMAL PROTECTION

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1. SUMMARY

The Gulf war created an unusual incentive to the rapid development and deployment of active cooling systems for defence personnel. One of the most successful efforts in this respect concerned a liquid-circulating system which departed from prior art in a number of significant ways. The system was deployed first by Canadian aircrew, and then by their British counterparts in the later stages of the conflict. The systems used by these forces are described, with an account of their physical and thermal characteristics, and an account of their performance in the field.

Very recent developments in electrically powered cooling units for microclimate use are also described. These new devices offer very real advantages in terms of power and space consumption. The impact they will have on air operations in extreme heat is discussed.

2. GULF WAR STIMULATES DEVELOPMENT

The potential benefits of active cooling systems, sometimes called "microclimate systems", for defence applications has been known for some time now, at least since the 1960's. Although the principles of such systems have remained basically the same over the last three decades, there have been recent improvements in the design details of active thermal cooling systems. These advances were stimulated not by any final realization that active cooling can extend the performance of defence personnel, but by the physical threat of actually having to face chemical weapons in desert conditions during the Gulf war. Chemical protective clothing impedes natural body cooling, and in 40C to 50C heat, aircrew would last no longer than one hour before becoming physically unable to fly, no matter how tough they were.

3. FIRST COMBAT USE

In the summer of 1990, the crew of Canada's 423 Squadron, flying shipborne Sea King helicopters, became the first air crew to use active personal cooling systems in combat. The urgency of the situation left no time to carry out extensive modifications to aircraft. Any microclimate system had to have very little or no impact on the aircraft itself. There wasn't time for much equipment development either. Whatever was applied had to be available and effective. Existing aircraft electrical systems could provide only limited power and the available space was also tight. Given restrictions of time, power, volume, and compatibility with existing aircraft and flight clothing, there was only one feasible system. Liquid-circulating heat transfer garments are easy to integrate with other clothing. Ice-based microclimate systems require minimal external power, none if their pumps are powered by battery, and their volume and weight are competitive with other systems for missions up to about four hours. Ice supply had been considered to be the drawback which prevented the fielding of such systems, but the Canadian helicopter crews were to fly from ships, and the ships' freezers could provide the ice needed. The Canadians opted for ice-based, liquid-circulating microclimate systems.

Figure 1 shows the system first deployed by the Canadian Forces. There are four basic parts, a heat transfer garment to remove metabolic heat, a passthrough assembly to penetrate the chemical garment (not shown), a tether to carry the coolant to and from the user, and a "cooling unit" to chill and circulate the coolant. The heat transfer garment is a long-sleeved shirt, not a vest, and it differs from prior art in a number of ways. The tubing is retained by continuous zig-zag stitching, tying it firmly to a stretch knit NOMEX fire-resistant fabric. Knit fabrics tend to shrink in the vertical direction when they are stretched horizontally. To allow for this movement, the tubing is applied in a sinusoidal pattern, a detail which results in a close fit to the user when the garment is stretched. An unusual feature is that there is no inner layer of fabric, rather the tubing rests directly against the skin to enhance the heat transfer. The shirt is thus not an additional layer to be worn, but rather takes the place of existing underwear. These shirts were designed for operation with ice-based cooling units which can provide very cold coolant, from 2 C to 10 C. Going against the accepted wisdom that

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coolant colder than about 15 C results in local vasoconstriction and discomfort, the design takes advantage of the lower temperature coolant and the elimination of an inner fabric layer to reduce the amount and size of the tubing. The result is a particularly flexible and thin design. Figure 2 shows the typical gross heat transfer rate for this type of garment, as a function of average coolant temperature. The cooling rate which was achieved in actual use by the Canadians has been estimated at 180 Watts, based on tests at Exotemp Systems and at the Institute of Aviation Medicine in Farnborough. (Ref. 1)

The passthrough relied on an opening in the charcoal-impregnated suit and a small sleeve in the liquid repellent overalls to prevent the ingress of chemicals. Quick-disconnect fittings outside and inside of the chemical garment allowed the crewmembers to disconnect from the cooling tether on one side, and the chemical overalls on the other.

The tether in the first Canadian systems was assembled from uninsulated plasticised polyvinyl chloride tubing, and connectors compatible with those on the passthrough and cooling unit.

The first cooling units were adapted from a unit developed for bomb disposal technicians, since it was a particularly compact design. Figure 3 shows this first unit. The coolant is straight water, and there is no heat exchanger. The warm return water contacts the ice itself to be chilled. The two litre polyethylene ice container was designed to accept cubed ice, but it was discovered in the field that it could be frozen solid if placed in the freezer at an angle to avoid the connectors mounted on the bottle. Even with this technique, the endurance of this container was rather limited, reportedly about 30 minutes in the field. Spare bottles were carried in flight and changed according to a predetermined schedule. (Ref.2)

The method of control for the system also departed from the previously accepted norm. Rather than adjusting the coolant temperature, the cooling rate was adjusted by varying the flow of coolant through an electronic pump speed controller.

4. CANADIAN RESULTS

In spite of the somewhat elementary nature of these first systems, the results in actual use were impressive. Canadian aircrew were able to fly two hour missions in full chemical protective gear, in 46 C ambient conditions (50 C to 60 C inside the aircraft). To record first hand impressions of the system's actual performance, the author interviewed Captain Greg Leis and Master Corporal Wayne Moran of 423 Squadron, two of the men who used the system in flights from the Athabaskan, a 280 class destroyer.

Each Sea King helicopter had a crew of four, and cooling systems were used whenever chemical garments were worn. When chemical gear was not required, the cooling systems were saved for higher ambient temperatures. The estimated operating time on each system was about 40 hours. Approximately 24 systems were put into use. There were no problems with skin irritation or other physiological effects. Both men noted that the cooling was enough to get the job done, and it was very much welcomed by the crews, but it was by no means excessive. Both would have used the interconnecting heat transfer pants had they been available to them. Sweating was still profuse at the level of cooling being provided. The two men's comments with respect to the schedule for changing ice were illuminating. The 30 minute cycle provided about 15 minutes of impressive cooling, starting with a wave of cooling that they could feel sweep over the body as the cold water entered the system. The performance faded towards the end of the cycle, leaving the aircrew to urge on the clock as 30 minutes approached. (This relatively short endurance was considerably improved with the systems used later by the British, for a number of reasons.)

The Canadians encountered little difficulty in providing ice. A meat locker in the ship's freezer was used at first. Later on, a large domestic type freezer was located in the maintainer's space for this use.

Figures 4 and 5 show results from a Canadian Forces Field Trial Questionnaire on the thermal comfort of the Chemical Defence Individual Protective Equipment (CD IPE) worn by flight crews of a number of aircraft in preparation for and during the Gulf conflict. (Ref. 3) Displeasure with the CD IPE alone is evident in Figure 4, and one can see the improvement with active cooling for Sea King pilots in Figure 5.

5. ROYAL NAVY AND ARMY EXPERIENCE

Following the successful Canadian experience, the UK Ministry of Defence acquired a larger number of Exotemp microclimate systems. These incorporated some significant advances in the state of the art, including one major innovation which made operation from land bases practical.

Figure 6 shows the flying parts of

the system supplied to the UK. The cooling unit was redesigned to allow operation on either aircraft power or on a slide-in rechargeable battery. The cooling unit's thermal insulation was improved, and the ice container was redesigned to allow it to hold more ice in the same 2 litre volume when frozen solid. The tether was insulated with a foam neoprene extrusion, and the tether coolant lines were made of butyl for enhanced chemical resistance. The garment was much the same, except the coolant entrance and exit were located on the chest, instead of at the side of the waist. These improvements resulted in an increased endurance to 60 minutes per ice bottle. The most important advance made however, concerned the means of providing ice.

The UK aircrews were to operate from hastily established land bases, not ships. There would be no guarantee of electrical power, and it would be important to be able to get any support equipment into place quickly by air or ground. Figures 7 and 8 show the solution chosen, the first mobile refrigeration systems (MRS) for microclimate use. Developed, manufactured, tested and shipped within 10 weeks, the MRS effectively removed the logistical impediments to using ice-based microclimate systems in the field. As a rule of thumb, each MRS is capable of supporting continuous cooling for 20 aircrew flying 8 hours per day.

Deployed by British forces in Operation Provide Comfort in northern Iraq and Turkey, these diesel-powered units proved quite successful. They are capable of freezing an entire load of 165 two litre ice bottles within 24 hours while in an ambient temperature of 50 C. There is also a temperature-controlled battery charging compartment which charges 24 batteries for cooling units in one hour.

Ease of transport was a key factor in the design of the MRS. Six will fit into a Hercules, two into a Chinook. As part of some quick trials before being deployed, one was transported by helicopter as an underslung load, and was reported to be quite stable when carried this way. They were designed with good ground clearance, an adjustable hitch, automatic surge brakes, and low ground pressure to make them suitable for towing behind a variety of ground vehicles, both off-road and at highway speed. Their towing performance was confirmed during a 28 hour road trip behind a four ton truck. They were found to be "very stable despite some very rough road surfaces". (Ref. 4)

6. CURRENT EFFORTS TO EXTEND THE STATE OF THE ART

Ice-based systems offer important advantages in terms of versatility, portability, and ease of application. However a system which uses an electrically-driven, vehicle-mounted cooling unit would offer certain logistical advantages. Interest in such designs remains high, and there are at least two initiatives now underway which promise to make this type of system practical.

Casey Copter of Montreal is working on a microclimate cooling unit which uses components similar to those found on existing aircraft vapour compression air conditioning systems. The compressor will be a standard commercial hermetic design, with the motor modified to 28 VDC. The projected performance is 630 Watts total cooling at 49 C ambient, and 18 C coolant delivery temperature, perhaps enough for a crew of four. The design weight is 20.5 kg, and the expected volume is 27 litres. Power consumption is projected to be 22 Amperes of 28 Volt DC power.

Figure 9 shows another new personal cooling system undergoing thermal mannequin testing in March of this year. This equipment is being developed under a US Army Natick Research, Development and Engineering Laboratory programme. The specific application for the programme is chemical handling, a dismounted soldier application, but the hardware which has been developed is quite close to that which would be needed for use aboard military vehicles, including aircraft. The project has resulted in some important advances in the state of the art.

The performance of heat-pumping cooling units, like those which use vapour compression refrigeration, in contrast to heat-absorbing cooling units, like those which use ice, depends heavily on the difference between the temperature of the coolant being delivered, and the ambient temperature into which heat is pumped. In an electric system, power consumption and size are usually critical. Other factors being equal, the power consumption of electrically-powered cooling units is reduced if coolant can be used at a higher temperature.

In designing an ice-based system, one can make use of coolant at close to freezing temperatures without any penalty. However garments for electrically-powered systems must be able to extract the required heat from the user with a coolant temperature somewhat closer to skin temperature. An efficient electrically-powered system will use garments with higher thermal performance, incorporating more

tubing and higher flow rates to effect the required cooling. The suit developed for the new vapour compression system is rated at 300 Watts net (375 Watts gross) heat removal with coolant at 18 C.
It is worth noting that such higher performance garments will also work when connected to ice-based cooling units. In fact they will work exceptionally well, but such performance is not usually needed and perhaps not even desirable with ice-based cooling.

The vapour compression cooling unit being used in Figure 9 is quite remarkable. Capable of providing 375 Watts of cooling with the garmentry described above in a 35 C ambient, it measures only 170 mm X 170 mm X 280 mm, and weighs just 5 kg. The unit has been designed for, and has been tested with R134A refrigerant. The power consumption is 150 Watts at 24 volts. The projected power consumption for 300 Watts of cooling at 50 C is 225 Watts. These specifications represent a significant overall advance in vapour compression type cooling units for microclimate systems.

7. IMPACT ON FUTURE AIR OPERATIONS IN EXTREME HEAT

The Gulf war experience showed conclusively that the use of liquid-circulating microclimate systems can restore the effectiveness of air crew operating under hot desert chemical warfare conditions. With a transportable microclimate support unit, like the MRS, effective ice-based personal cooling can be easily extended not only to aircrew flying in unmodified aircraft, but just as importantly, to portable applications for support personnel on the ground.

Recent developments in vapour compression cooling units designed especially for microclimate use suggest that with a single unit of about 8 litres volume and 5 kg weight, it will be possible to prevent heat stress in hot desert conditions for two air crewmembers dressed in chemical garments, with a power demand of 8 Amperes of 28 Volt power. Aboard many existing helicopters, finding 16 Amps of spare current and 16 litres of space to look after a crew of four is not out of the question, and there are many other military aircraft and ground vehicles which could benefit from this new hardware. Such electrically-powered systems will be preferred whenever practical aboard most aircraft and ground vehicles. With the advent of these smaller vapour compression cooling units, attempts to use thermoelectric technology for personal cooling will be largely abandoned, because of the much higher power consumption with thermoelectrics.

Ice and electrically-powered cooling units, heat transfer garments, and other hardware such as the MRS freezer trailer can easily be made intercompatible. By integrating such components into a chemical protective system designed for the air unit, it is now practical to maintain the effectiveness of air operations under extremely hot CW conditions. Personnel working within such a system may find themselves connecting to different cooling units, and donning various interconnecting heat transfer garments, depending on the task to be done and the heat load expected.

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2. Interviews conducted by the author January 11, 1993 at CFB Shearwater with Captain Greg Leis and Master Corporal Wayne Moran of the Canadian Forces 423 Squadron.

3. Tremblay, R., "AC4 Field Trial Questionnaire", Technical Memorandum, MLSD 93/001, Canadian Forces Defence and Civil Institute of *Environmental Medicine*, North York, Ontario, Canada, Feb. 1992.

4. Bradley, "OP Provide Comfort - Cooling Vest Report", Annex D to TURK/1, Royal Navy June 1991.

Figure 1 - The First Microclimate System to be Used in Combat.

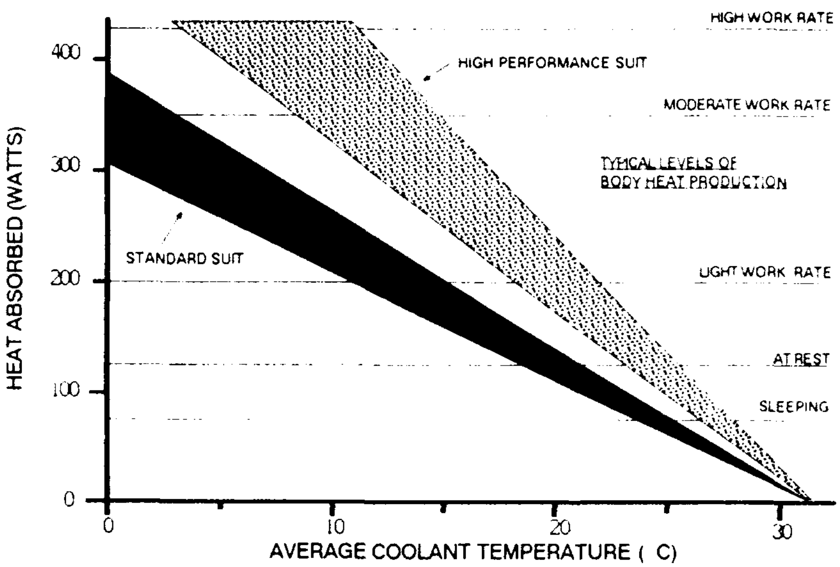

Figure 2 - The heat transfer performance of standard Exotemp heat transfer garments. Shown here are typical results for a complete suit, shirt, pants, and hood. A shirt alone will achieve about 60% of the performance shown.

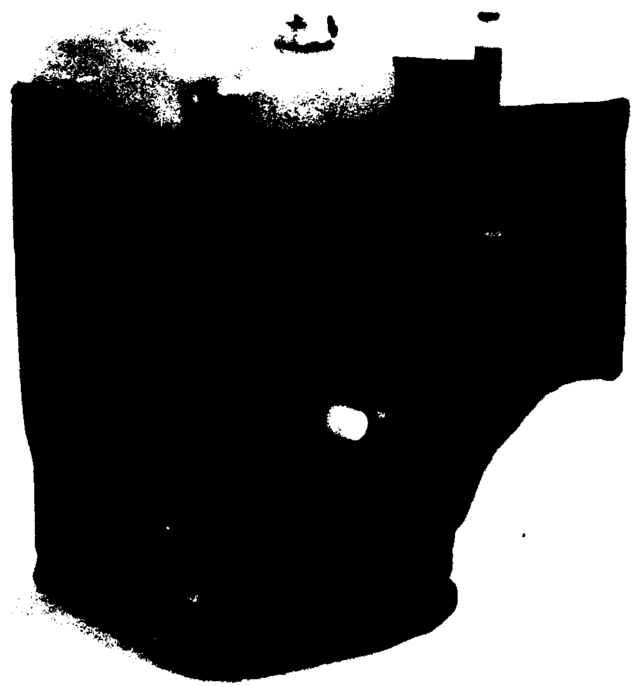

Figure 3 - The Exotemp BD1 Cooling Unit.

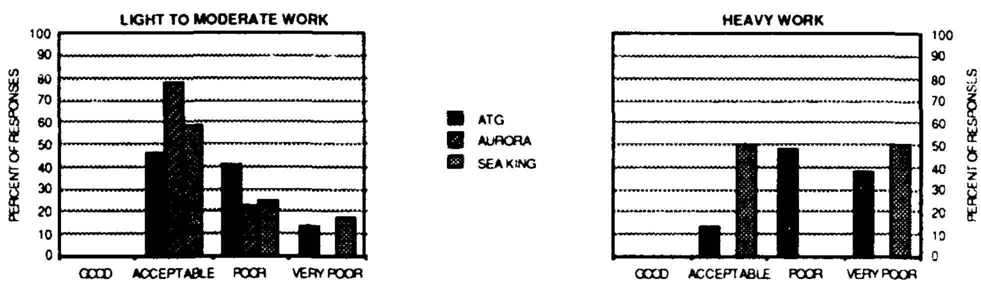

Figure 4 - Results of survey of Canadian Forces aircrew who have flown with Chemical Defence Individual Protective Equipment (CD IPE) - **NO COOLING.** (Ref. 3)

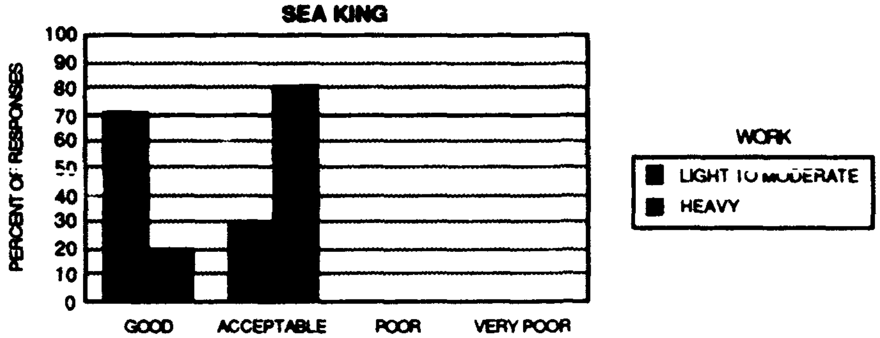

Figure 5 - Results of survey of Canadian Forces aircrew who flew with the CD IPE with active cooling during the Gulf War.

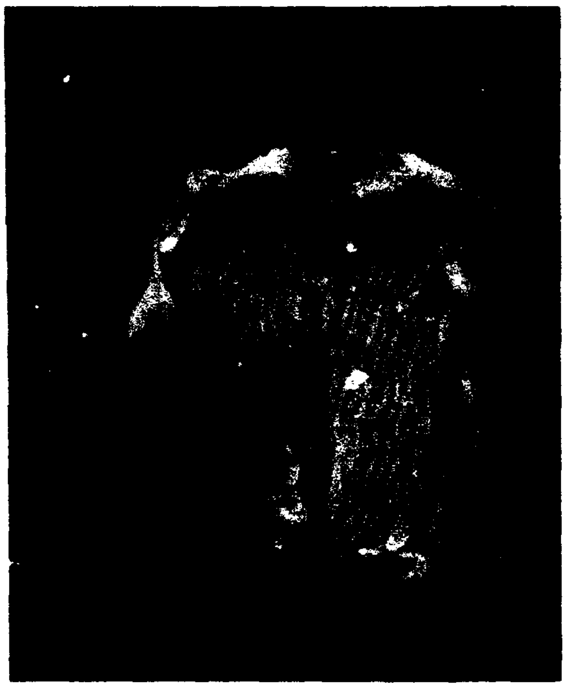

Figure 6 - The Exotemp CD2 Microclimate System - Used by the Royal Army and Navy during the Gulf Conflict.

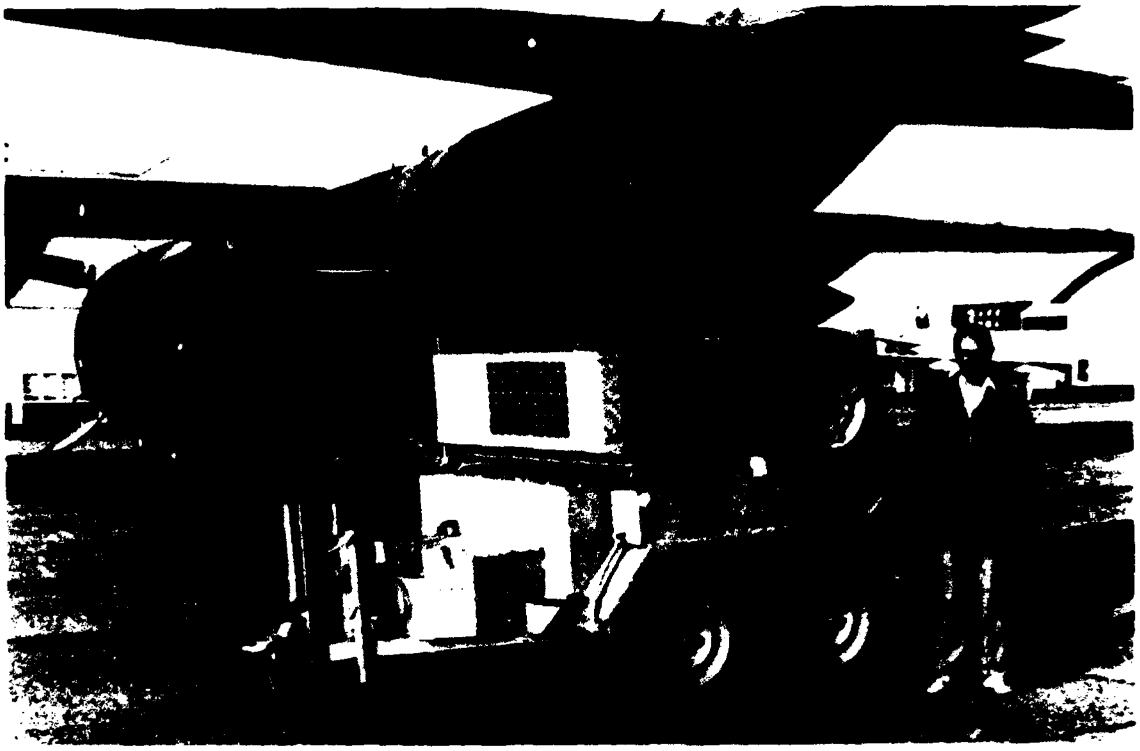

Figure 7 - The Diesel Powered MRS - A Mobile Support Unit for Ice Based Microclimate Systems.

Figure 8 - Developed for use by British forces, the MRS produces enough ice and charges enough batteries every day for 165 man-hours of portable personal cooling.

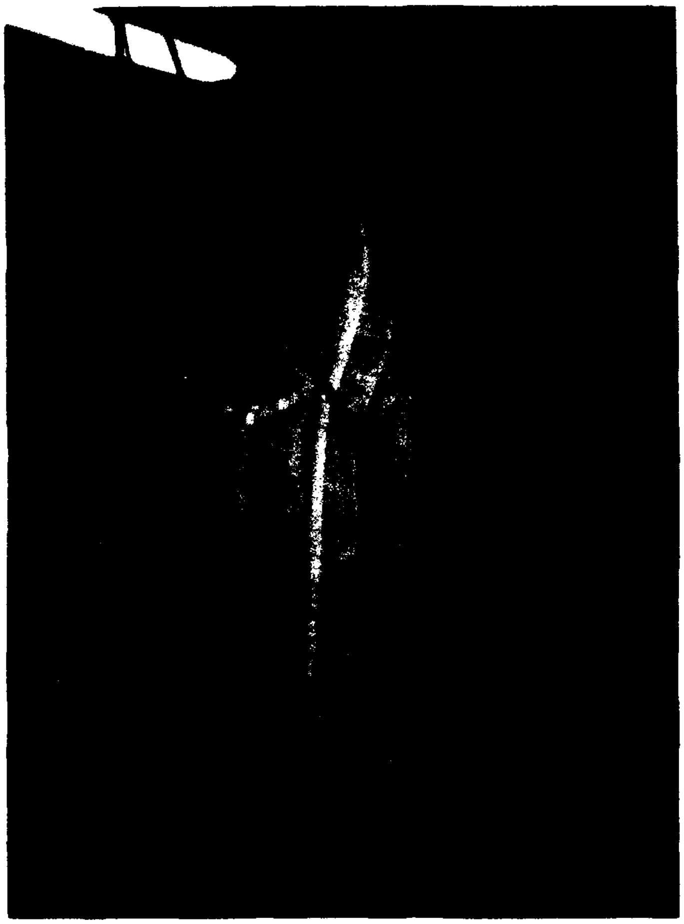

Figure 9 - Mannequin Testing of the STEPO Electrically-Powered Personal Cooling System

TEST OF A NEW PROTECTION SUIT IN A CLIMATIC CHAMBER

by

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SUMMARY

Within the framework of the research and technology programme, a whole-body protection suit with integrated helmet has been developed by the Dornier Company. The thermo-physiological capabilities of this suit were tested by Division IV - Ergonomics - of the German Air Force Institute of Aviation Medicine. Ambient temperatures higher than those normally to be expected in the cockpit were chosen intentionally. In spite of this fact, pulse rates remained below the limiting value and the average rise in core temperature was insignificant. Loss of weight through sweating amounted to approximately 1 % of body weight. It proved possible to remove 82 % of this sweat by means of ventilation.

Based on the results of the questionnaires on subjective sensibility, no prejudice to well-being and no negative effects in respect of the capability to act were established with regard to the testing of the whole-body protection suit under laboratory conditions.

1 INTRODUCTION

The thermal load of jet crews has for a long time posed a serious problem. As early as 1965, Wing demonstrated the decline in mental performance in an excessively hot environment. At the same time, Taliaferro demonstrated that, in such an environment, the tolerance of +Gz acceleration decreases owing to dehydration. Both forms of impairment could be avoided, or at least reduced, by means of appropriate air-conditioning. Recently published tests show that the creation of a microclimate around the pilot himself would be preferable to air-conditioning of the whole cockpit for reasons of weight and energy-saving. Next-to ˈhe-body micro air-conditioning can be achieved with appropriately designed exposure clothing and accompanying aggregates. Heat exchange in such exposure clothing takes place by means of a liquid or gas transport medium.

Figure 1: Whole-Body Exposure Suit

The Dornier Company, now a member of DASA, has developed a whole-body exposure suit in accordance with these considerations. In this whole-body exposure suit, a microclimate is activated by means of air flow. It is intended that the exposure suit on hand should provide anti-g as well as NBC protection in the final development phase.

The whole-body exposure suit is designed to reduce the number and weight of exposure clothing parts. The presentation will show the whole-body exposure suit in detail together with the results of the tests performed in the climatic chamber. The whole-body exposure suit consists of the suit itself and a helmet. The suit with its attached socks covers the whole body. The sleeve ends and the neck band are sealed with rubber collars. The ventilation air tube enters the suit on the left. The waste air outlets are at the sleeve ends. The suit includes a removable inner suit. Whereas the inner suit is made from fabric providing water vapour permeability, waterproof fabric is used for the outer suit.

Figure 2: Integrated Helmet System with NBC Collar (Prototype)

Figure 3: Hoses for Leg Ventilation

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

Ventilation air feed hoses lead down the inside of each leg and supply the air to the suit at the inner calf. The conditioned air then flows up around the legs, around the trunk and finally along the arms, to leave the suit at the ends of the sleeves. The back of the suit is cushioned from the shoulder to the base of the thigh. This cushioning ensures that the seat contact area is continuously ventilated when the pilot is sitting.

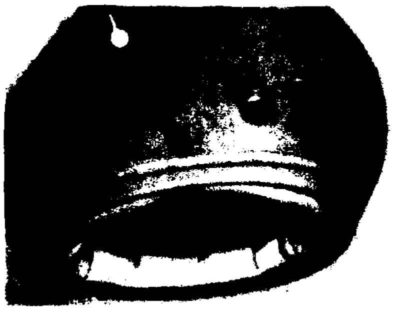

Figure 4: Integrated Helmet System with Inflatable Sealing

The helmet is designed as an integral helmet. The helmet opening is sealed with an inflatable rubber collar, thus creating a closed helmet interior. Respiratory air is fed in at the upper part of the helmet and flows via the double-layered shell of the helmet to the upper edge of the visor, from where it flows down the visor to the lower helmet edge. Due to the appropriate volumetric flow through the helmet and the space available behind the visor, the pilot is provided with sufficient tidal volume. The helmet is connected to the suit with an NBC protective covering.

Like the suit, the gloves also consist of an inner and an outer glove. In order to avoid any disturbing factors, all necessary glove seams are on the back of the fingers and the tips of the outer gloves are made of rubber.

2 METHOD

In order to test the whole-body exposure suit under realistic conditions, a sequence of tests was conducted in a climatic chamber. These tests were designed to prove that a harmful ambient climate can be endured in the suit over an exposure time of 2 hours. All climatic parameters of the tests are shown at Table 1.

Enviroment	Exposure Suit
Air temperature: +50°C ±2°C	**Helmet:**
	Air temperature: +30°C ±5°C
Relative humidity: 20 - 30 %	Ventilation: 120 l/min ±20l/min
	Dewpoint: -10°C
Wind speed: 1 m/s	
	Suit:
	Air temperature: +25°C ±5°C
	Ventilation: 220 l/min ±30l/min
	Dewpoint: -10°C

Table 1: Climatic Parameters

The tests were performed on 11 healthy male pilots aged between 21 and 45 years. During his 2-hour stay in the chamber, the test person had to perform several tasks.

Step	Time (min)	Activity
1.	5	Rest
2.	10	Questionnaires
3.	5	Rest
4.	10	PAULI Test
5.	5	Questionnaires
6.	5	Rest
7.	10	Bicycle ergometer
8.	5	Questionnaires
9.	5	Rest
10.	10	PAULI Test
11.	5	Questionnaires
12.	5	Rest
13.	10	Bicycle ergometer
14.	5	Questionnaires
15.	5	Rest
16.	10	PAULI Test
17.	5	Questionnaires
18.	5	Rest
19.	5	COOPER/HARPER

Table 2: Climatic Chamber Test Program

He was subjected to a physical work load of 1 Watt per kg body mass by means of the bicycle ergometer, and to a mental work load by means of calculation tests and questionnaires about his general feeling of thermal well-being. The test person was able to relax between the different working phases

A modified Martin Baker ejection seat was used as the test person's seat and the test person was strapped into it. The bicycle ergometer was placed in front of this ejection seat. On top of this ergometer was a writing board with a test calculator and the questionnaires for the paper and pencil tests.

Figure 5: Test Facility

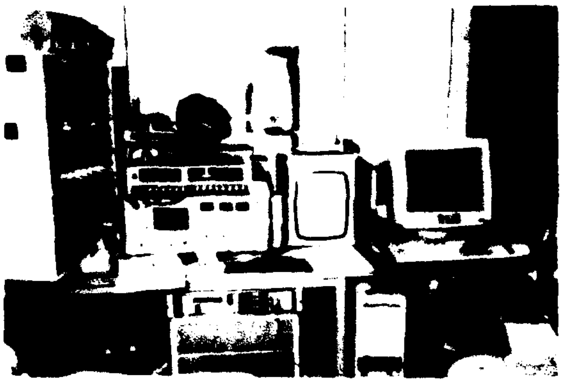

Figure 6: Control Area

In accordance with our objectives, the following criteria were used to evaluate the sustainability of the suit in a raised ambient climate:

1. Heart rate
2. Skin temperature and core temperature
3. Loss of weight
4. Subjective evaluation

The criteria defined for abandoning an individual trial were as follows:

- pathological ECG
- cardiac arrythmia
- pulse rate increases to 200 min^{-1} minus age
- increase of core temperature above 38.5 °C for 15 min or single increase above 39 °C
- break-off at the request of the test person

3 RESULTS

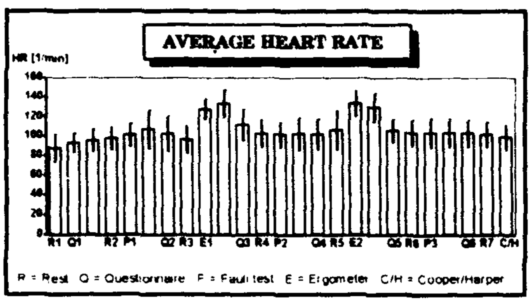

Figure 7: Average Heart Rate

The average heart rate is shown in Figure 7. The bars represent mean values and the extended brackets show the standard deviation. Each bar contains the values recorded at 5 minute intervals.

The heart rate increased during the test period of 2 hours on average from 94 beats per min at test begin to 101 bpm at test end. Ergometer loading increased the heart rate on average to a value of 135 bpm, as had been expected. Comparison of the average heart rate of 94 bpm recorded immediately before the test with an average rate of 78 bpm measured at rest the day befor , demonstrated that the 45 minute dressing procedure had triggered both a physical and psychological pre-test reaction. Comparison with the heart rate recorded at the end of the test demonstrated that the increase in strain caused by the time spent in the chamber was only minor. The individual heart rate also remained in every case below the pulse rate criterion for abandoning the test of 200 min^{-1} minus age.

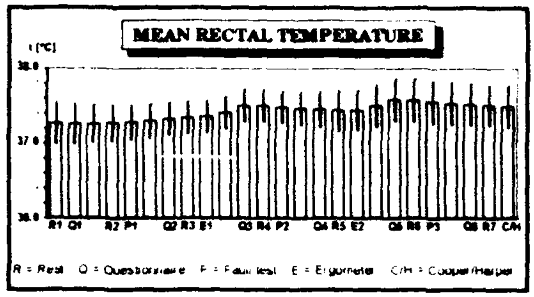

Figure 8: Mean Rectal Temperature

A slight tendential increase in rectal temperatures was recorded up to the first ergometer loading as shown in Figure 8. Rectal temperatures increased during ergometer loading and reached their highest levels during the 5 minute period following ergometer loading. Thereafter, a slight decrease in rectal temperature was recorded at the end of every 5 minute interval. The average increase in rectal temperature recorded in all tests was 0.2 °C.

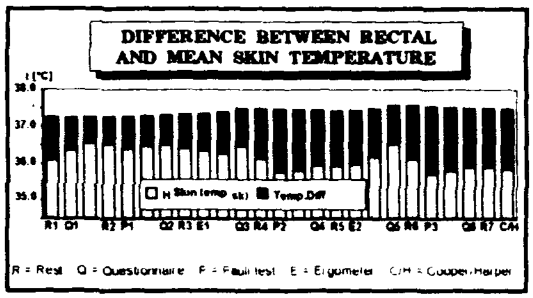

Figure 9: Difference Between Mean Rectal and Mean Skin Temperature

The mean skin temperature was determined from the skin temperatures measured using the Ramanathan formula, shown in Figure 9, as a light bar. The seemingly unsteady behaviour of the average skin temperature is explained by the fact that following each ergometer loading, a slight rise in skin temperature is succeeded by a distinct fall. The average skin temperature recorded at test end was some 0.2 to 0.3 °C below the temperature recorded at test begin. Since the average rectal temperature increased slightly during the same period - shown in Figure 9 as a dark bar - the difference between rectal and average skin temperature rose from just under 1 °C at test begin to approx. 1.5 °C at test end.

As the test person was weighed nude, dressed in underwear, and with all his equipment before and after the time spent in the climatic chamber, it was possible to calculate the loss of weight through sweat and evaporation. On average, 120 g of sweat were absorbed by the underwear, 50 g by the whole-body exposure suit and 810 g were lost to waste air. This means that, on average, each test person lost 1.0% of his body weight. Based on the Craig index, which is calculated from the perspiration rate per hour together with the changes in rectal

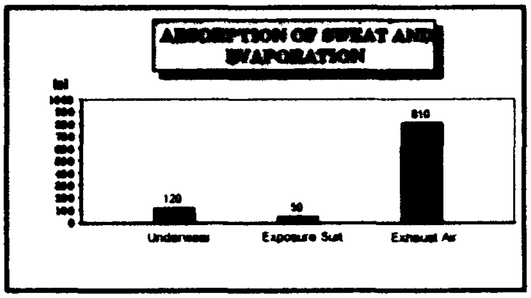

Figure 10: Absorption of Sweat and Evaporation

temperature and heart rate, the load experienced during the time the test person stayed in the increased ambient climate can be classified as moderate. The 1% loss of sweat also remained below the value of 2%, for which Taliaferro established a limited +Gz acceleration tolerance in his tests.

The following Figure shows the degree of subjective sensibility (1 = low 7 = high) recorded in respect of various categories (y-axis) and in all test phases (x-axis). It can be seen that the sensation of thirst (black columns) and sweating (grey columns) increased in the course of the tests, the values recorded levelling out at an average of 4 points, which is in the uncritical (safe) range. Sensibility to cold (white columns) was below average (low) throughout the test period.

The subjective sensibility described of three categories above represent intrinsical components of the all-embracing category "general well-being" (diagonally-lined columns), which was well above average prior to test begin, decreasing only insignificantly in the course of the tests to level out at average at test end.

Both the subjectively experienced ability to concentrate (vertically-lined columns) as well as physical stress capacity (horizontally-lined columns) were only insignificantly affected by the duties performed while wearing the whole-body protection suit over a period of 120 minutes. The ratings varied between 7 and 5 points, and must be seen as higher than average.

To summarise, it can be said that, based on the results of the questionnaires on subjective sensibility, no prejudice to well-being and no negative effects in respect of the capability to act were established with regard to the testing of the whole-body protection suit under laboratory conditions

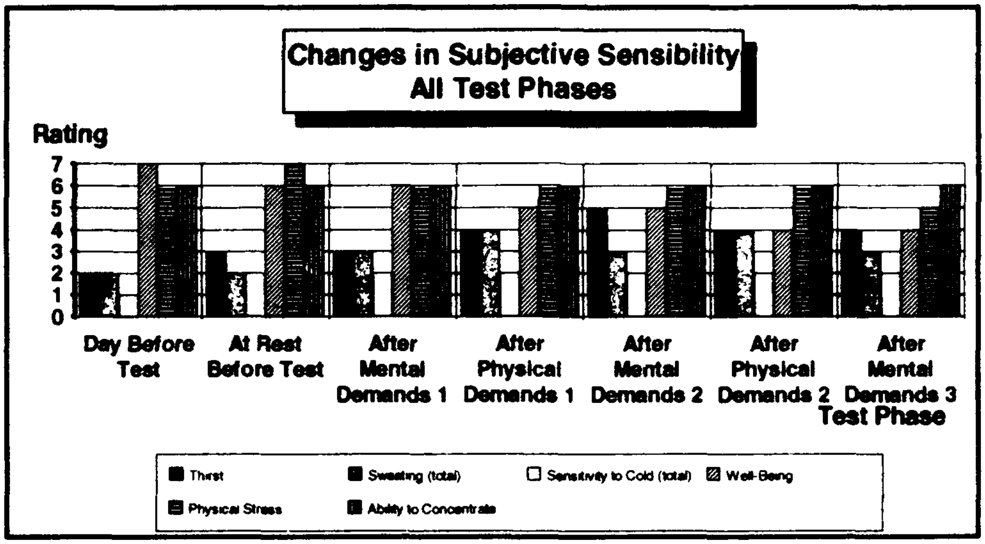

Figure 11: Changes in Subjective Sensibility

4 CONCLUSIONS

The whole-body exposure suit currently in development is capable of protecting pilots from harmful ambient conditions for a period of up to at least 2 hours. Due to the efficient air cooling provided by the whole-body exposure suit, the increase in physiological reaction of the test persons during their stay in the chamber was relatively small. No test person requested test abandonment for thermal reasons. All test persons thought that the air flow in the suit and helmet was very pleasant, and this fact is also supported by the psychological test results. Based on this results continuation of the development of this innovative suit-helmet concept is considered to be justified.

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The use of liquid and air microclimate conditioning systems to alleviate heat stress in helicopter NBC operations

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SUMMARY

The effects of microclimate cooling on aviator performance and physiology in Nuclear, Biological, and Chemical (NBC) Individual Protective Equipment (IPE) were evaluated in the USAARL UH-60 research flight simulator. Sixteen male aviators flew the simulator in two temperature conditions, 35°C and 41°C, both at 50% relative humidity (RH). Two thermoelectric conditioning units were used, one providing cooled blown air, the other cooled water to the aviators. At each temperature they flew for up to six hours in NBC IPE with no cooling, air cooling, and liquid cooling.

There were significant improvements in flight performance as a result of the cooling, more so at the higher temperature. There were also differences between the two cooling systems at 41°C, with the air system producing statistically significant lower flight error rates. Survival time was based on the length of time each subject stayed in the condition before reaching physiological withdrawal criteria or exercising their option to retire early. There were considerable increases in survival time with the use of microclimate cooling. The mean survival time at 35°C was increased from 285 minutes without cooling to 358 minutes with the liquid system. At 41°C the improvement was even more dramatic, from 79 minutes with no cooling to 333 minutes for the air system. There were significant differences between the two cooling systems at 41°C with the air system producing longer survival times. Rectal temperature, mean skin temperature, and heart rate were monitored and showed significant improvement with both conditioning systems compared with the no cooling conditions. The liquid system produced the most benefit. Dehydration occurred in all conditions, but was significantly reduced by the use of cooling.

INTRODUCTION

United States Army doctrine for the integrated battlefield (AirLand Battle doctrine) depends in large measure upon aviation for support, mobility, and fire power. Current threat information and AirLand Battle doctrine indicate that combined arms crews must be prepared to operate for as long as 72 hours in the presence of a chemical agent threat. Army aviation is at serious risk in the chemical environment since the ability of aviators to control their aircraft may be disrupted. The probable outcome of an unprepared crew facing a chemical agent would be the loss of pilots, crew, cargo, passengers, aircraft, and mission failure. Pilots cannot don their chemical protective clothing, the individual protective equipment (IPE) in flight because of limited space, distraction from the flying task, and lack of adequate warning of a chemical threat. It is likely, therefore, that aircrew will be required to wear full IPE, including mask, throughout all flights, whenever there is a significant threat of the use of chemical agents by an enemy.

Several studies have examined the physiological penalties on pilots of wearing NBC IPE (1,2,3,4,5,6,). The psychological and performance effects of wearing NBC protective clothing also have been widely studied (7, 8,9,10,11).

The value of a variety of microclimate cooling systems in improving the psychological and physiological responses to exercise heat stress with NBC uniforms has been demonstrated in a number of studies (12,13,14,15). Vallerand et al. (16) compared the effects on alleviating heat strain of a commercial liquid microclimate cooling system with an air chiller system at 37°C, 50% RH. They found significant advantages with the air system in terms of rectal temperature, heart rate, and thermal comfort, which they attributed to the beneficial effects of the greater evaporative cooling produced by the air system. Thornton (17) carried out a short subjective assessment of commercially available microclimate

Presented at an AGARD Meeting on 'The Support of Air Operations under Extreme Hot and Cold Weather Conditions', May 1993.

cooling systems in conjunction with an Army wide study (18) for possible use by troops involved in Operation Desert Storm.

The objective of the current study was to assess how the deleterious effects on flight performance and physiology of flight operations in NBC IPE can be alleviated by the use of two microclimate cooling systems.

METHODS

Simulator

The USAARL UH-60 helicopter simulator is an aeromedical version of the standard UH-60 training simulator with the addition of an environmental control system (ECS) to regulate the cockpit thermal environment by specifying dry bulb temperature (T_{db}) (68-105°F) and relative humidity (RH) (50-90%). It is linked to a real time data acquisition system on a DEC VAX 11/780 computer, which can record and analyze aircraft flight parameters and pilot inputs.

The simulator is mounted on a 60-inch stroke synergistic hydraulic motion system. This provides six degrees of freedom of motion to induce acceleration cues in the lateral, longitudinal, vertical, pitch, roll, and yaw axes over a 60-degree range. The simulator uses actual earth mapping and terrain data as the basis for digital imagery generating visual scenery. Scene viewing is through a three-channel, four-window digital image generator (DIG) system. Three separate video scenes are sent to four cathode ray tube (CRT) displays. Forward looking scenery is split between two front CRTs, with scenery also presented to the left and right side window CRTs.

An on-board biomedical equipment cabinet contains a diagnostic patch panel, the ECS control panel, a 16-channel signal conditioner, and the AC/DC power distribution panels which power the biomedical research data acquisition equipment. The patch panel provides 16 input connections for biomedical signals. These connect to cabinet mounted physiological preamplifiers which can be used to boost the level of the signals.

Environmental conditions

The environmental conditions used were 35°C (95°F), 50% RH for one condition (T1), and 41°C (105°F), 50% RH for the other (T2). The maximum dry bulb temperature that could be specified was 105°F, and 50% the minimum RH. The solar radiation load was simulated by using infrared lamps to produce a radiant heat load on the helmet of the subjects of 130 watts per square meter (Wm^{-2}), and 100 Wm^{-2} over the legs. The simulator ECS uses degrees Fahrenheit for its controls and settings, and the conditions therefore will be described in °F in the remainder of this report. All other temperatures are reported in degrees Celsius.

Subjects

Subjects for the study were 16 volunteer male Army aviators, between the ages of 21 and 39 and in good health, as determined by a flight surgeon using a self-administered written medical history questionnaire and their medical records. Apart from age and sex, the only other selection criterion was that subjects should not require visual correction for flight. This was applied because of the difficulties and delay that would have been encountered in providing visual correction for the M43 mask. They were asked to refrain from alcohol use for the duration of the study.

Clothing assemblies

The Aircrew Uniform Integrated Battlefield (AUIB) is under development at the Natick Research Development and Engineering Center (NRDEC), Natick, Massachusetts, as a two-piece garment combining both thermal and chemical protection for aviators. It is constructed of sage green 4.5-ounce plain weave Nomex-Kevlar/polytetrafluoroethylene (PTFE) laminated outer shell and charcoal impregnated polyurethane foam/tricot laminated liner. There is a sleeved port in both sides to allow passage of a microclimate cooling hose, and tapes to seal around it. It is worn with the M43E-1 aircrew member's protective mask (AMPM), and the survival armor recovery vest (including packets) (SARVIP).

The M43E-1 mask consists of a bromobutyl facepiece with an integrated butyl hood and skirt. Overpressure is provided within the mask by a blower assembly, a battery-powered motor which blows air to the hood through two standard NBC filters. Some of the air flow is directed over the inside of the lenses to prevent misting, and some over the scalp to provide cooling. It incorporates a microphone and drinking tube.

Microclimate cooling systems

Two thermoelectric microclimate cooling systems, designated as the aviator microclimate conditioning system (AMCS), have been developed in parallel by Aviation Systems Command (AVSCOM), St Louis, Missouri. One is based on air conditioning, the other liquid. The air cooled version of the AMCS is used with the second generation version of a single piece cooling vest, designed by NRDEC. It is worn over a tee shirt, immediately underneath the AUIB. Contaminant-free air is introduced to the vest through the air hose which attaches to a female connector on the side of the vest and has a quick disconnect attachment on the other end to interface with the aircraft subunit hose connector. The cooler supplies air at a flow rate of 5.66 litres per second (12 cfm) for each of four stations, providing a theoretical cooling capability of 250 watts. Subjects were allowed to control their own flow rate, by selecting the high, low, vent, or off setting. This was as the result of a positive decision at the start of the study to use realistic cooler conditions rather than regulating flow rate and temperature to constant values. In practical terms, there will always be some variation from the specified values, especially when several aircrew share the same cooling source. The vent setting allows the blower fan to be used without thermoelectric cooling, and this was used on one of the test days to simulate cooling failure.

The liquid cooling unit was used in conjunction with the Exotemp vest and hood. The Exotemp vest is a long-sleeved turtle neck shirt. The garments are made of Nomex fabric and are lined with thin plastic tubing (1/8 inch outside diameter) to carry the coolant. The vest was worn in place of an undershirt. The hood was used to give the subjects the advantage of head cooling, in the knowledge that, in practice, it can be disconnected if not necessary or desired.

Physiological data

Throughout the experiment, deep body temperature, skin temperature, and heart rate were recorded at 0.5-second intervals, on the VAX computer while the subjects were in the simulator, otherwise on a Squirrel 1202/42 data logger at 1-minute intervals. The same data appeared on a meter at the medical observer's position, independent of the VAX system, in case of computer failure.

The medical observer took manual recordings at 5-minute intervals to provide data backup, and to ensure adequate monitoring of critical values.

Deep body temperature

Deep body temperature was measured using a rectal thermistor inserted by the subjects, 10 cm beyond the anal sphincter. The rectal probes were pre-calibrated by comparison to a YSI reference probe. Any which differed by more than 0.2°C over the range 36-40°C were rejected.

Skin temperature

Skin temperature was measured at four sites, chest (T_{chest}), upper arm (T_{arm}), inner thigh (T_{thigh}) and outer calf (T_{leg}), using thermistors held in position by an elastic harness. Mean skin temperature ($\bar{T}sk$) was calculated after Ramanathan (19) using the formula:

$$(\bar{T}sk) = 0.3(T_{chest}) + 0.3(T_{arm}) + 0.2(T_{thigh}) + 0.2(T_{leg})$$

This made no allowance for the fact that the chest thermistor in the air system, and both chest and arm thermistors with the liquid vest, are on areas receiving direct cooling. With the small number of sites, it was considered impractical to apply any further weighting on he basis of cooled area, and the limited number (16) of physiological data channels available in the simulator precluded any increase.

Heart rate

Heart rate was recorded from ECG Ver-med electrodes and an R-wave counter (Boisig Instruments).

Weight loss

Subjects were weighed naked, then fully clothed before each run, and clothed, then dry naked after. This enabled calculation of weight loss and evaporative sweat loss. They were allowed liberal access to drinking water at all times, including during flight in the NBC IPE through the M43 mask drinking tube. Water canteens were weighed, and the weight drank used in the estimate of dehydration. Any urine voided between subject weighings was collected, weighed, and used likewise.

Pilot flight performance data

The simulator flight profile has been described in detail elsewhere (20). A deliberate decision was made to use the same flight profile in order to allow comparison of results between the two studies. It was designed to, as far as possible, represent a realistic tactical scenario. Within that, at regular intervals, were embedded manoeuvres which had to be flown accurately to allow scoring of performance by measuring deviation from assigned values for various flight parameters. It consisted of 1 hour of tactical low level flight, followed by 1 hour of upper air work. The automatic flight control system (AFCS) was disabled halfway through the upper air work to increase pilot workload. Control of the aircraft alternated between both pilots at specified intervals during flights, to allow assessment of two subjects in each flight. When it was necessary to withdraw one pilot for any reason, it was possible to continue assessing the other using the simulator operator as his copilot.

During the copilot's non-handling phase of each flight, flying-related tasks were minimized to leave 20 minutes available in each 2-hour sortie for performance assessment battery (PAB) testing, using the Paravant RHC-88 hand-held computer. Space does not permit the reporting of those data, but the results of an additional questionnaire, the 'fatigue checklist,' (21), which provided a subjective assessment of fatigue, was programmed into the RHC-88, and those results are reported.

Aircraft preparation

During field operations of helicopters, the metabolically most demanding activities occur not during flight, but in associated activities on the ground such as preflight inspections and refuelling (22). Therefore, to make this study more realistic, an initial metabolic load was devised for the subjects in the form of a simulation of preflight activities. Data are available for the average energy expenditure (370 watts) of preflighting similar sized aircraft (23), so that it was possible to simulate this activity by exercising to a similar rate of work on a treadmill (4.8 km per hr, 0^{o} slope). While there was no facility available in which this could be done with accurate climatic control, local heating was used in the treadmill room, in an attempt to duplicate the simulator conditions as closely as possible. WBGT was recorded during this phase, together with heart rate, and deep body temperature.

Environmental data

The simulator cockpit dry bulb temperature (T_{db}), wet bulb temperature (T_{wb}), and black globe temperature (T_{bg}) were measured and output to the VAX computer at 1-minute intervals. The WBGT was calculated according to the formula:

$$WBGT = 0.7T_{wb} + 0.1T_{db} + 0.2T_{bg}$$

Experimental design

The experimental design is shown in Table 1. It consisted of 2 days training on the experimental flight profile, the first in the standard flight suit, the second in the NBC IPE. Eight hours training has been demonstrated to be more than adequate for this particular flight profile (Thornton et al., 1992). At each temperature there were three test conditions: no cooling, air cooling and liquid cooling. In addition, at T2 only, there was a fourth test condition in which the air system was used in its vent mode, to simulate failure of the cooling system. The order in which the conditions were administered was randomized, with the restriction that none of the 3 days which resulted in the most heat stress (days 3 4 and 9 in Table 1) was allowed to fall on consecutive days, to minimize any possible cumulative effects of heat stress or dehydration. The convention for abbreviated names for the conditions used in the remainder of this paper is shown in the last column of Table 1.

Data analysis

Flight performance data

The flight profile was divided into nine separate maneuver types. Some of the maneuvers were further subdivided, the hover maneuvers into low or high, and others into whether the AFCS was disabled or not. In most cases, statistically significant differences were found between the subdivisions of the divided maneuvers, necessitating separate analysis, e.g., between hover altitude error for the 40-foot hover, compared with the 10-foot hover. Each maneuver was scored for up to five different parameters which vary with the maneuver type. For example, navigation was scored for heading, altitude, slip, and roll while hover turn was scored for altitude only. Some maneuvers were repeated several

times in each flight, and the flight was repeated three times per test day. In all, there were 69 separate flight maneuvers per test day with up to 5 relevant parameters each.

Flight performance data were recorded twice a second for 16 parameter channels, and the data were processed to produce a single root mean square (RMS) error value for each channel appropriate to each of the 9 maneuvers. The RMS values were obtained using the squared deviation from the reference value for that particular parameter. These then were summed, and divided by the total number of samples. Finally, the square root was calculated, so that the units for the RMS value corresponded to those of the original parameter. The result thus is similar to the standard deviation, except that it is calculated using differences from the ideal value rather than from the mean.

Plotting the RMS error for maneuver parameters of one type sequentially throughout a test day showed no appreciable increase in error rate with time in almost all cases, as shown in the results section. This was confirmed by statistical analysis, using the methods described below. The mean error rate for each of the 55 maneuver parameter combinations, e.g., hover-heading, hover-altitude, therefore was used in the final data analysis.

Analysis of variance (ANOVA) was undertaken on the RMS error values meaned for all 16 subjects, using the SAS/STAT general linear models (GLM) procedure and Duncan's multiple range test for evaluating posteriori comparisons (24). Condition and subject number both were included in the model. Repeated measures ANOVA was not appropriate because of the unequal cell size caused by subjects dropping out early on the hotter days. This method also was used to test the relationships between maneuver subdivisions and flights, as described above. The alpha level was set at 0.05 for each comparison.

The performance data were analyzed in a number of different ways in an attempt to allow for the variations in cooler performance described below. Results were analyzed for subjects using the better (right, pilot's) side of the cooler only and analysis was undertaken for subjects 12 onward (8 subjects), to allow for the improved performance of the air cooler at that stage.

The short survival time for the 105 nil condition meant that sufficient data were available for analysis only for the first hour of flight. The upper airwork data therefore do not include this condition.

Survival time

The differences in survival times between the various conditions were analyzed by ANOVA, using the Greenhouse-Geisser correction because of the large number of degrees of freedom. The Newman-Keuls test was applied to determine post hoc comparisons (25).

Fatigue checklist

The fatigue checklist was scored using a BASIC program which converted responses into a score. A mean value then was calculated for each of the four administrations of the checklist in each test condition, and used in the analysis. ANOVA was used to analyze the results in the same way as for survival time.

Physiological data

The physiological data on the VAX were processed by sampling them at 5-minute intervals throughout the flight, first for the pilot, then the copilot, and appending both sets of results into one file. The resulting data file was converted into an SPSS system file, and the results were plotted using SPSS Graphics. The data were tested using regression analysis, and plotting the 99% predicted confidence intervals.

Water balance was calculated in terms of weight, percentage body weight, and rate of weight change. The latter was done in order to better compare subjects who survived varying periods of time. It was done by dividing the total weight of, for example, dehydration, by the time from starting the treadmill work to doffing the uniform. ANOVA was used to test for differences in fluid balance between conditions. Sweat loss calculations were not corrected for respiratory water loss.

RESULTS

Cooler performance

Liquid cooler

Calculations were performed on the temperature and flow rate data to derive the cooling capacity in watts, by multiplying mass flow rate by specific heat of water by the

temperature difference. The results ranged from 101 to 352 watts per subject, with the right side consistently getting the greater share of the cooling. They can be compared with a theoretical total capacity for the unit under the same conditions of 248 watts per person at 95°F and 220 watts at 105°F.

Air cooler

Calculations of the actual cooling capacity of the air unit were made by comparing enthalpy at vest inlet and outlet using an assumed flow rate of 5.66 liters per second, a vest efficiency of 63% and the measured skin temperatures. The actual values ranged from 142 to 300 watts per subject, with the right side again doing better in all cases. Some of the variation was due to a series of technical problems with the air conditioning unit, which were not remedied completely until after completion of the first half of the study. The air vest is designed to produce 250 watts at both temperature conditions.

Flight performance

Examples of the flight performance data as analyzed for individual maneuvers are shown in Figures 1-4. Figure 1 shows the RMS error plotted against maneuver number (three runs of two maneuvers) for hover and hover turn at 95°F. The saw tooth effect is caused by the difference in size of the RMS error for low and high hover. Collapsing across condition and hover height, there were no significant differences between the three run numbers.

Figure 2 demonstrates the mean of the RMS error for hover turn in each condition, for both low (10 ft) and high (40 ft) hover turns. For low hover turn, altitude, the error for 105 nil was significantly greater than all other conditions. For high hover turn, altitude, the error for 105 nil and 105 vent was significantly greater than the 95°F conditions. The error for 105 air was significantly greater than 95 air and 95 liquid.

There were no significant differences between the two cooling systems for the data shown in Figure 2. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems. Collapsing across condition, the error for altitude was significantly greater in the high hover than in the low hover.

Figure 3 shows the RMS error plotted against maneuver number (three runs of one maneuver) for left descending turn at the 95°F conditions for rate of turn, airspeed, roll and rate of descent. Collapsing across condition, there were no significant differences between the three run numbers for four parameters. For roll, the error was significantly greater on the first run than the third.

Figure 4 contains the mean of the RMS error for all left descending turn maneuvers in each condition and each subject. For rate of turn, error rate was significantly lower for 95 air and 95 liquid than for 105 vent and 105 liquid. For airspeed and rate of climb, there were no differences between conditions. For roll, the error for 95 air and 95 liquid was significantly lower than 105 vent and 105 liquid. There were no significant differences between the two cooling systems for the data shown in Figure 4. When the data were examined for pilots only, and for subjects 12 onward only, there were still no differences between the systems.

A summary of the flight performance data statistics is shown in Table 2. There are 55 combinations of maneuver and parameter, each of which has a mean RMS error score for each of the 7 conditions. The convention used for indicating significant differences between groups is that used by SAS in their multiple comparisons testing, in which the same letter denotes means that are not significantly different. In those lines which contain different letters, the means grouped as A are always higher than those grouped as B, B higher than C, and so on. The alpha value was set at 0.05.

At 95°F, there were eight cases in which the performance error was significantly lower for liquid cooling than no cooling, and seven in which air cooling produced a better performance. There were no significant differences between the flight performance for the two cooling systems. At 105°F, the subjects did not survive long enough without cooling to obtain any meaningful flight performance data for comparison. Using the vent condition as a basis for comparison, bearing in mind that it in itself provides considerable relief compared with no cooling, there are 18 cases in which the error was significantly lower with liquid cooling than vent

only. There were 13 cases in which air cooling produced significantly better performance than vent only. There were three cases at 105°F in which the performance with the liquid system was significantly better than the air system.

To allow for the poorer performance of the air cooler unit in the early stages of the study, a separate comparison was made using only the last eight subjects. There were no differences in flight performance between the cooler systems at 95°F, but at 105°F there were 11 examples of the air system producing significantly better flight performance than the liquid, and none of the liquid system producing better performance than the air system.

Survival Time

The simplest measure of the ability to operate in NBC protective clothing is 'survival time,' that is the length of time that the conditions can be endured before the subject removes himself from the experiment, or the physiological criteria are met. The overall survival times are shown in Table 3. Subjects who reached the physiological limits for withdrawal are indicated. The subjects who quit voluntarily did so usually complaining of headache, nausea, or both. One subject quit during both liquid sessions because of painful 'hotspots' on his head caused by the tubes in the cooler cap. On the 105°F run for the final two subjects, the air cooler failed. Their values therefore are not included in the summary statistics nor the graphs. Subjects 14 and 15 were a day late starting the study, and the vent condition was dropped to allow their participation. The means are graphed in Figure 5, together with the minimum survival time for each condition.

A significant condition effect was present, ($F(6,78) = 53.32$, $p < 0.0001$). The mean survival time at 95°F without cooling was 285 minutes, the minimum 118. Only one individual in either case failed to complete 6 hours exposure with cooling at 95°F. The post hoc analysis indicated that the increase in survival time for both cooled conditions over the uncooled was statistically significant, (air $p < 0.05$, liquid $p < 0.01$), but the two cooled conditions cannot be separated statistically.

At 105°F without cooling, the mean survival time was only 79 minutes, with a minimum of 40 minutes. The additional evaporative cooling provided by the vent air increased mean survival time significantly to 150 minutes ($p < 0.01$), with a minimum of 66 minutes. With cooling, the air system produced a significantly better survival time of 333 minutes ($p < 0.01$) compared with 294 minutes ($p < 0.01$) for the liquid system, and a large difference in minimum times, 225 and 113 minutes respectively. The increased survival time with cooling compared with vent and uncooled conditions is statistically significant. The two cooled conditions cannot be separated statistically.

Because of the differences between cooling capacity for the two sides of both coolers, the mean and minimum survival times were also computed for the better (right) side. The differences between the two conditions at both temperatures are now minimized, and cannot be separated statistically. Analyzing data for the last six subjects only, to take account of the poorer air cooler performance in the first half of the study, there is a significant effect for condition, ($F(6,30) = 49.78$, $p < 0.001$). Post hoc analysis reveals a significant difference between the mean survival times for the two cooled conditions at 105°F (360 minutes for air, 256 for liquid), ($p < 0.01$) but none at 95°F.

Physiology

Rectal temperature

Figure 6 shows the mean rectal temperature by condition for the 6 hours during which subjects were in the simulator at 95°F, plotted at 5-minute intervals. There is an obvious difference between the mean rectal temperature without cooling and with either conditioning system, and a smaller difference between the two cooling systems, with the liquid system producing the cooler temperatures. The trend is for the mean rectal temperature with the liquid system to continue falling throughout the test period, whereas the air-cooled curve levels after 2 hours to maintain a temperature which is elevated by 0.5°C. The drop in the no cooling curve is due to the loss of subjects from the data pool as they were withdrawn, those who left having a higher rectal temperature, leaving the mean value for the remainder lower.
The significance of differences between the various curves was determined by plotting the confidence intervals for selected curves. Lack

of overlap of the 1% confidence interval of one curve with the 99% confidence interval of another being taken to indicate a significant difference. The differences on the treadmill were analyzed by selecting the first available simulator value for each variable in each condition and performing analysis of variance. This indicated that there were no significant differences between conditions for the rectal temperatures.

Figure 7 shows the mean rectal temperatures in the simulator at 105°F. The stepped appearance in the uncooled curve is again due to loss of subjects. The advantage of vent air over no cooling is shown by the lower values, though N is only 3 beyond 200 minutes, and 1 after 280 minutes. There is no significant difference between the air and liquid curves, but that is due in part to the higher (but statistically insignificant) initial value for the liquid curve due to the larger skin area insulated by the liquid vest and hood. There is an initial rise for both systems, though after 2 hours the temperature starts to fall for the liquid system but keeps on rising for the air system. Selecting data for the last eight subjects only, or pilots only, made little difference to the results.

Mean skin temperature

Figure 8 contains the mean skin temperature data for the simulator at 95°F. Unlike the rectal temperature, there is no rise in skin temperature with time without cooling, though both cooling systems show an initial fall, followed by a steady rise after 90 minutes for the air system and 180 minutes for the liquid, with the liquid system consistently providing the lower values.

Figure 9 shows the same data for 105°F. Here the uncooled skin does show an increase in temperature with time. The liquid system appears to provide a sustained decrease in mean temperature, while the temperature with the air system starts to rise after 150 minutes.

Heart rate

The simulator heart rates at 95°F are in Figure 10. The results are similar to the rectal temperatures with the uncooled condition producing a steady increase with time, which was not diminished as the hotter subjects dropped out. Both cooling conditions reduce the initial exercise-induced elevation, with the liquid system producing a lower overall level. Figure 11 shows the same curves for the 105°F conditions. There is little, if any, benefit from the vent condition compared with no cooling. There is no significant difference between the cooling systems, though the tendency is for the liquid values to be slightly higher.

Water balance

Figure 12 graphs the water balance data in terms of weight (kg) for dehydration, sweat loss, water drunk, and urine voided at 95°F, and Figure 13 shows the same information at 105°F. ANOVA demonstrates a main effect for condition for dehydration ($F(6,90) = 4.86$, $p = 0.0002$), for sweat production ($F(6,90) = 17.58$, $p < 0.0001$), and water consumption ($F(6,90) = 6.84$, $p < 0.0001$). For dehydration, the only significant difference within temperature groups, is between 95 nil and 95 air ($p < 0.05$). The weight of sweat loss was significantly greater for 95 nil than both 95 air and 95 liquid ($p < 0.01$) and greater for 95 air than 95 liquid ($p < 0.05$). The weight of water drunk was significantly greater at 95°F without cooling than with the liquid ($p < 0.01$) or air cooling system ($p < 0.05$).

The absence of significant differences at 105°F is because of the smaller exposure time for the no cooling condition which does not allow as much total dehydration to occur. The total dehydration for all the conditions at 105°F was twice that found at 95 nil. Much of this was caused by a reluctance among subjects to drink water from canteens which quickly warmed as it sat in the simulator cockpit. Some subjects complained of nausea if they drank.

Figures 14 and 15 show the data for dehydration and sweat loss as a rate (g/minute), to allow for the different exposure times. There was a main condition effect for dehydration ($F(6,90) = 15.70$, $p < 0.0001$), for sweat production ($F(6,90) = 40.80$, $p < 0.0001$), and water consumption ($F(6,90) = 17.91$, $p < 0.0001$). None of the dehydration differences at 95°F is statistically significant. The 105 nil condition produced a significantly greater rate of dehydration than 105 vent ($p < 0.05$) and both 105°F cooled conditions ($p < 0.01$), and the 105 vent rate was significantly higher than 105 air ($p < 0.01$). For sweat rate, 95 nil was significantly higher than both cooled

conditions at 95°F ($p < 0.01$). The sweat rate at 105 nil was significantly higher than all other conditions ($p < 0.01$), and at 105 vent, significantly higher than the two cooled conditions ($p < 0.01$). The significant differences in the rate of water consumption within temperature are between 105 nil and all other 105°F conditions ($p < 0.01$), and between 95 nil and 95 liquid ($p < 0.05$).

In the same way that other data have been analyzed separately to allow for the effects of poor air cooler performance in the study, so have the water balance data been analyzed for the last eight subjects only. There were no significant differences within temperature for the dehydration data by weight. There was a condition main effect for sweat production ($F(6,42) = 15.17$, $p < 0.0001$), and water consumption ($F(6,42) = 11.18$, $p < 0.0001$). The weight of sweat loss at 95 nil was significantly greater than 95 air and 95 liquid ($p < 0.01$). The weight of water drunk at 95 nil was significantly more than at 95 liquid ($p < 0.01$), and 105 air was significantly more than 105 nil ($p < 0.05$).

The rate data for the last eight subjects show a main effect for condition for dehydration ($F(6,42) = 37.30$, $p < 0.0001$), for sweat production ($F(6,42) = 15.10$, $p < 0.0001$), and water consumption ($F(6,42) = 9.06$, $p < 0.0001$). There is a significant difference in the rate of dehydration between 105 nil and all other 105°F conditions ($p < 0.01$), and between 105 vent and 105 liquid ($p < 0.05$) and 105 air ($p < 0.05$). The rate of sweat loss at 95 nil was significantly greater than for 95 liquid ($p < 0.05$) and 95 air ($p < 0.01$). The rate of sweat loss at 105 nil was significantly greater than all other 105°F conditions ($p < 0.01$) and the rate for 105 vent was significantly greater than 105 air ($p < 0.05$). The rate of sweat loss at 105 liquid was significantly greater than 105 air ($p < 0.05$). The rate at which water was drunk was significantly greater at 95 nil than 95 liquid ($p < 0.05$), and at 105 nil compared with 105 liquid ($p < 0.05$).

There were no significant differences in urine output for any of the analyses. The summary statistics for water balance are in Table 4.

__Fatigue checklist__

The mean scores for the fatigue checklist are plotted in Figure 16 for 95°F and Figure 17 for 105°F. Session one is the baseline, completed after dressing in the uniform of the day. Once the simulator flight was over, even if the subject retired early, no further checklists were completed. The results are therefore a mean of survivors only. At 105°F, as so few subjects survived long enough without cooling to complete session two, that condition is not included in the graphs or the analyses. Both the graphs show a main effect for session ($F(2,30) = 22.96$, $p < 0.0001$).

Figure 16 shows a marked improvement in fatigue score for both systems compared with no cooling ($p < 0.01$), and liquid is consistently better than air, though the difference is not significant. Figure 17 shows that the fatigue score with cooling is significantly better than with vent air ($p < 0.01$), but there is no difference between cooling types.

Using only subjects 12 onwards, there is again a main effect for session ($F(2,14) = 10.01$, $p = 0.0022$). For the 95°F data, both systems still provide better cooling than none at all, though the difference is only significant for the liquid ($p < 0.05$), but there is now no difference between systems. At 105°F the fatigue score is better for air than liquid, though the difference is not significant.

__Environmental temperature__

The temperatures recorded in the simulator cockpit and treadmill room are shown in Table 5. The temperatures in the treadmill room were as hot as could be achieved with the use of space heaters, and showed considerable variation, related to the outside air temperature and the efficiency of the Laboratory's air conditioning system. The RH, calculated from a psychrometric chart using the mean values in the table, was 23%. The recorded temperatures are slightly higher than those selected on the simulator ECS, due probably to the differing positions of the Wibgets and the ECS sensors. RH at 95°F was 53% and at 105°F, 55%.

__DISCUSSION__

__Conditioning systems__

The reliability and performance problems with the air conditioning unit were a cause for concern and produced major difficulties in

interpreting the data. It was decided at the start of the study to accept any minor variations in performance due to differences in flow rate between individual subjects, as this would reflect the case in the aircraft. Similarly, major differences produced by the subjects selecting a lower cooling rate, or even no cooling at all, were deemed preferable to enforcing a single controlled level of cooling. As the main investment was in measuring flight performance, it was felt important to allow the subjects to choose their own comfort level, the potential for impaired performance being just as great if the subjects were over-cooled as if they were under-cooled.

These assumptions were made on the basis that both cooling units would perform as advertised, and clearly this was not the case. On the other hand, for the second half of the study, the developers of the equipment had the air cooler running to the best performance they could get from it (as confirmed by tests of the unit on return to their facility after the conclusion of the study), albeit still not up to its theoretical maximum. It was compared to the liquid conditioner in identical usage conditions, and it is concluded that the data for the last eight subjects at least are valid for comparisons between the systems.

Flight performance

The effects on flight performance of cooling compared with no cooling at 95°F showed significant improvement for less than 15% of parameters scored for both systems, despite significant reduction in physiological parameters, including rectal temperature and heart rate. At 105°F without cooling, the subjects did not survive long enough to obtain any meaningful data, but using the vent condition as a basis for comparison, the liquid system provided significantly better results in approximately 25% of cases. It can be inferred that the comparison with no cooling at all, for the short time that it can be endured, would be even more significant. Using only the data for the last eight subjects to optimize the effects of the air conditioning unit, there were no significant differences in flight performance between the two systems at 95°F, but at 105°F the air system produced significantly better performance in 20% of cases.

Survival time

The most striking demonstration of the advantages of microclimate cooling to the aviator is obtained from considering the effect on survival time. Without cooling, the mean survival time at 95°F was 285 minutes. With cooling, the mean time was in excess of 350 minutes for both systems. At 105°F without cooling, the mean survival time was only 79 minutes. Air cooling increased it to 333 minutes, liquid cooling to 294 minutes. Some of the difference between systems derives from the problems two of the subjects reported with discomfort from the liquid cooling cap rather than differences in cooling effect.

Physiology

There was a significant rise in rectal temperature in the 95°F uncooled condition, with two subjects reaching the physiological withdrawal limit of 39°C. Both cooling systems provided adequate control of the rectal temperature, with the liquid producing lower temperatures and a more sustained cooling than the air. The mean rectal temperature with the air system started to rise later in the test period. At 105°F without cooling, there was a dramatic rise in rectal temperature, with all but three of the subjects reaching 39°C. There can be no doubt that all subjects would have become serious heat stress casualties had they been forced to remain in the IPE at that temperature. Both cooling systems produced big improvements, but the air system again resulted in an increase in rectal temperature with time. Three subjects using the air system and one using the liquid (all in the first half of the study) reached the physiological withdrawal criteria. The vent mode produced a moderate improvement in rectal temperature. The treadmill exercise period produced a small but statistically insignificant greater rise in mean rectal temperature with the liquid vest compared with the air vest. With a longer ground wear period before flight, this might have produced more of a problem.

The mean heart rate also was much reduced by cooling at both temperatures. At 95°F, the liquid system produced the lower mean, but at 105°F, the air system had the lower value, though it rose slightly with time and tended to converge with the liquid results.

A significant degree of dehydration occurred at 95°F without cooling. The

rate of dehydration at 95°F was reduced to less than half the uncooled rate by both cooling systems. The rate of sweating also was considerably reduced by cooling, to a slightly lesser extent by the air system, which drives the rate of evaporation to achieve its effects. The amount of dehydration at 105°F for all conditions was twice that at 95°F without cooling. Much of this was due to the reluctance of the subjects to drink warm water. The rate of sweating and dehydration was reduced greatly by cooling.

Subjective fatigue

Both temperatures produced a steady increase in subjective fatigue with time. There was a big improvement caused by the use of cooling, and there were no significant differences between the systems.

CONCLUSIONS

When reading the conclusions of this study, it should be borne in mind that the conditions were not worst case. The flight profile was undemanding and well-rehearsed, with no true emergencies or unplanned deviations, and the environmental conditions are not the most extreme that can be encountered. Furthermore, the AUIB is not in service, and the current NBC IPE can be expected to produce a greater heat load.

1. The use of microclimate cooling produced a large increase in the time subjects were able to survive in NBC IPE in both hot conditions.

2. A significant improvement in flight performance was obtained by the use of microclimate cooling.

3. There was no evidence of flight performance decrement with increasing time in the environment, up to the 6 hours tested.

4. Subjects experienced a considerable degree of heat strain without cooling, as shown by their rectal temperature and heart rate, which was prevented completely at 95°F and partially at 105°F.

5. Microclimate cooling produced big reductions in the rate of sweat loss and dehydration.

6. The liquid system was a little better than the air system in its prevention of heat strain.

7. The air system was a little better than the liquid system in reducing flight performance error.

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Table 1.
Experimental design.

Day	Condition	Abbreviation
1 -	training, no heat	
2 -	training, no heat	
3 -	50% RH, 35°C (95°F)	95 nil
4 -	50% RH, 41°C (105°F)	105 nil
5 -	50% RH, 35°C (95°F) air	95 air
6 -	50% RH. 35°C (95°F) liquid	95 liq
7 -	50% RH, 41°C (105°F) air	105 air
8 -	50% RH, 41°C (105°F) liquid	105 liq
9 -	50% RH, 41°C air, blower only	105 vent
10 -	spare in case of delays	

Table 2
Flight performance data statistical summary

		Condition						
Maneuver	Parameter	95 Nil	95 Air	95 Liq	105 Nil	105 Air	105 Ven	105 Liq
1 Navigation	Heading	C	C	BC	BC	AB	A	BC
	Altitude	B	B	B	A	A	A	A
	Slip	B	B	B	A	B	B	B
	Roll	B	B	B	A	B	B	B
2a Hover	Altitude	BC	BC	C	A	BC	ABC	AB
(10 ft)	Heading	A	A	A	A	A	A	A
2b Hover	Altitude	B	B	B	AB	B	A	B
(40 ft)	Heading	A	A	A	A	A	A	A
3a Hov turn (10 ft)	Altitude	B	B	B	A	B	B	B
3b Hov turn (40 ft)	Altitude	CD	D	D	A	ABC	AB	BCD
4a Right	Rate of turn	A	AB	B		A	A	A
standard	Altitude	AB	AB	B		AB	AB	A
rate turn	Airspeed	AB	BC	C		AB	AB	A
(AFCS in)	Roll	A	AB	B		AB	AB	A
	Slip	BC	AB	BC		ABC	C	A
4b Right	Rate of turn	B	B	B		B	A	B
standard	Altitude	BC	C	C		AB	A	BC
rate turn	Airspeed	B	BC	C		B	A	B
(AFCS out)	Roll	AB	B	B		B	A	B
	Slip	A	A	A		A	A	A
5 Left	Rate of turn	ABC	C	C		BC	A	AB
descending	Airspeed	A	A	A		A	A	A
turn	Roll	AB	B	B		AB	A	A
(AFCS out)	Descent Rate	A	A	A		A	A	A
	Slip	A	A	A		A	A	A
6 Descent	Heading	B	B	AB		A	A	B
(AFCS out)	Airspeed	B	C	C		B	A	B
	Roll	C	D	D		B	A	CD
	Descent Rate	B	C	C		B	A	B
	Slip	C	BC	BC		A	A	AB
7a Left	Rate of turn	BC	BC	C		ABC	A	AB
standard	Altitude	AB	B	AB		A	AB	A
rate turn	Airspeed	A	A	A		A	A	A
(AFCS in)	Roll	AB	AB	B		AB	AB	A
	Slip	A	A	A		A	A	A
7b Left	Rate of turn	AB	AB	B		A	A	A
standard	Altitude	A	A	A		A	A	A
rate turn	Airspeed	B	B	B		B	A	B
(AFCS out)	Roll	ABC	BC	C		AB	ABC	A
	Slip	A	A	A		A	A	A
8 Climb	Heading	A	A	A		A	A	A
(AFCS in)	Airspeed	AB	C	BC		AB	AB	A
	Roll	B	B	B		B	A	B
	Climb rate	B	B	B		AB	A	A
	Slip	A	A	A		A	A	A
9a Straight	Heading	A	A	A		A	A	A
and level	Altitude	AB	B	B		A	AB	A
(AFCS in)	Airspeed	BC	C	C		AB	BC	A
	Roll	B	E	B		AB	A	B
	Slip	AB	AB	B		AB	A	B
9b Straight	Heading	AB	C	BC		ABC	A	BC
and level	Altitude	AB	C	BC		B	A	B
(AFCS out)	Airspeed	B	B	B		B	A	B
	Roll	B	C	C		B	A	C
	Slip	BC	C	BC		AB	A	ABC

Table 3
Survival time (minutes)

Sub	95 nil	95 air	95 liq	105 nil	105 vent	105 air	105 liq
3	360	360	360	40*	113*	360	360
4	225*	360	360	55*	66*	360	360
5	118	249	360	74*	89	225	312
6	330	360	360	74*	201*	242*	360
7	220	360	360	82*	180	360	360
9	149	360	360	50	150*	315	271
10	295*	360	360	130*	202	322*	197*
11	260	360	360	142	360	322*	360
12	360	360	330	60*	115	360	290
13	360	360	360	105*	115	360	360
14	360	360	360	82*		360	113
15	330	360	360	69*		360	258
16	257	360	360	58	85	360	155
17	360	360	360	90*	125*	360	360
18†	360	360	360	65*	259	300**	205
19†	310	360	360	65*	288	300**	360
Mean	285	353	358	79	150	333	294

† Data not included in mean
* Reached physiological criteria
** Run halted due to cooler failure.

Table 4.
Summary statistics for water balance.

	Initial Wt (kg)	Dehydration Wt (kg)	Dehydration %	Dehydration Rate (g/min)	Sweat loss Wt (kg)	Sweat loss %	Sweat loss Rate (g/min)	Drink Wt (kg)	Urine Wt (kg)
95 nil									
Mean	82.75	1.10	1.33	4.99	3.03	3.67	9.94	2.01	0.08
Std	8.17	0.96	1.21	5.35	0.89	1.10	3.38	0.78	0.16
95 air									
Mean	82.57	0.54	0.65	1.86	1.58	1.95	4.14	1.27	0.22
Std	8.22	0.35	0.42	1.20	0.50	0.69	1.27	0.79	0.40
95 liquid									
Mean	82.54	0.52	0.62	1.74	1.02	1.24	2.62	0.69	0.18
Std	8.18	0.28	0.33	0.93	0.26	0.30	0.65	0.30	0.42
105 nil									
Mean	82.46	0.94	1.14	17.06	2.05	2.51	19.55	1.13	0.02
Std	8.08	0.84	0.98	13.98	0.58	0.72	6.53	0.81	0.05
105 air									
Mean	82.60	0.87	1.06	3.10	2.50	3.04	6.81	1.73	0.11
Std	8.24	0.69	0.84	2.35	1.09	1.34	2.60	1.02	0.27
105 liquid									
Mean	82.58	1.22	1.46	5.77	2.58	3.15	8.63	1.40	0.04
Std	8.19	0.63	0.73	3.73	0.85	1.08	3.89	0.71	0.09
105 vent									
Mean	81.99	1.23	1.49	11.94	2.32	2.85	13.23	1.17	0.07
Std	6.84	0.68	0.84	7.29	0.56	0.73	6.31	0.95	0.18

Table 5.
Environmental temperatures (°C).

	Dry bulb	Wet bulb	WBGT
Treadmill	34.92	20.03	24.29
Simulator			
95°F	34.63	27.04	29.85
105°F	39.62	31.82	34.67

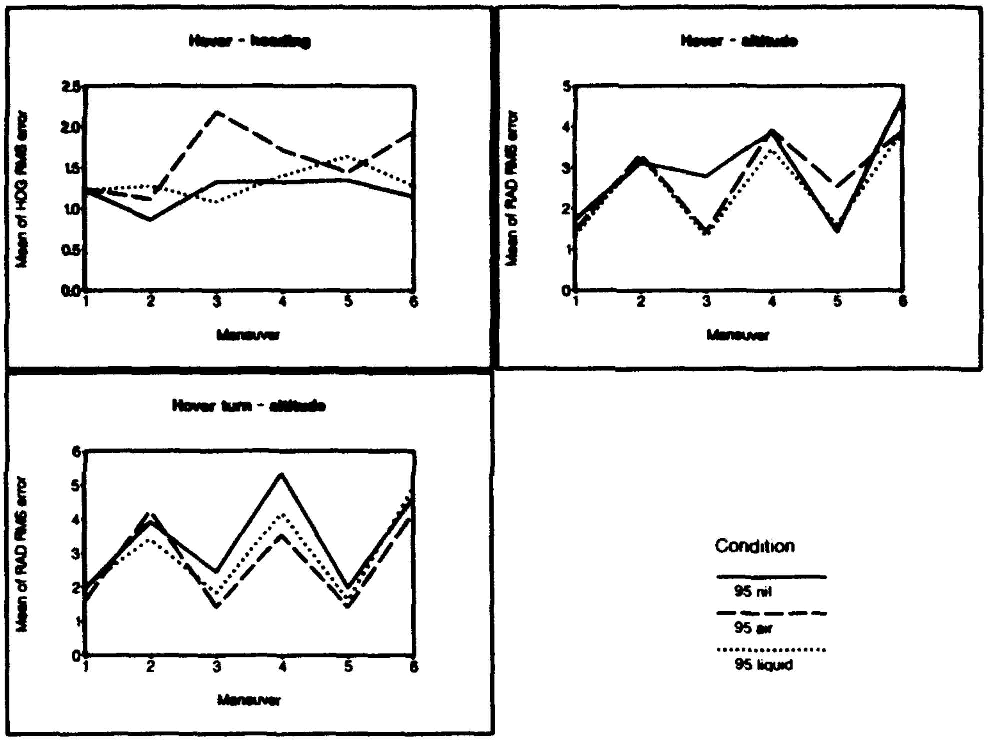

Figure 1. Hover and hover turn RMS error by maneuver, 95°F.

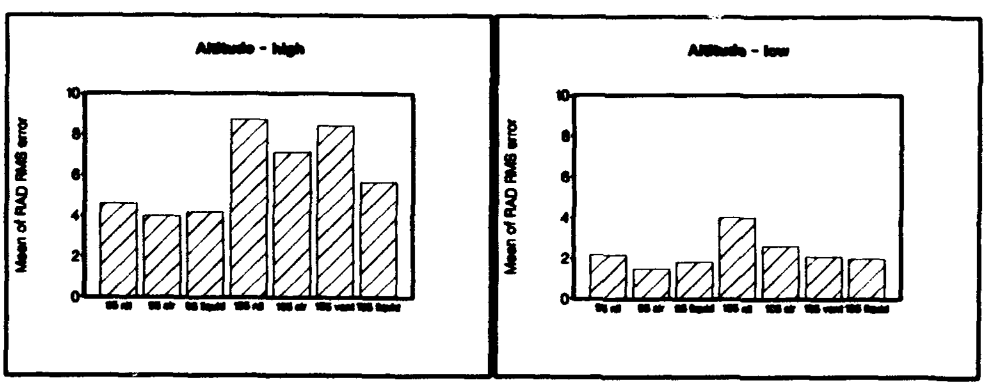

Figure 2. Hover turn mean RMS error by condition.

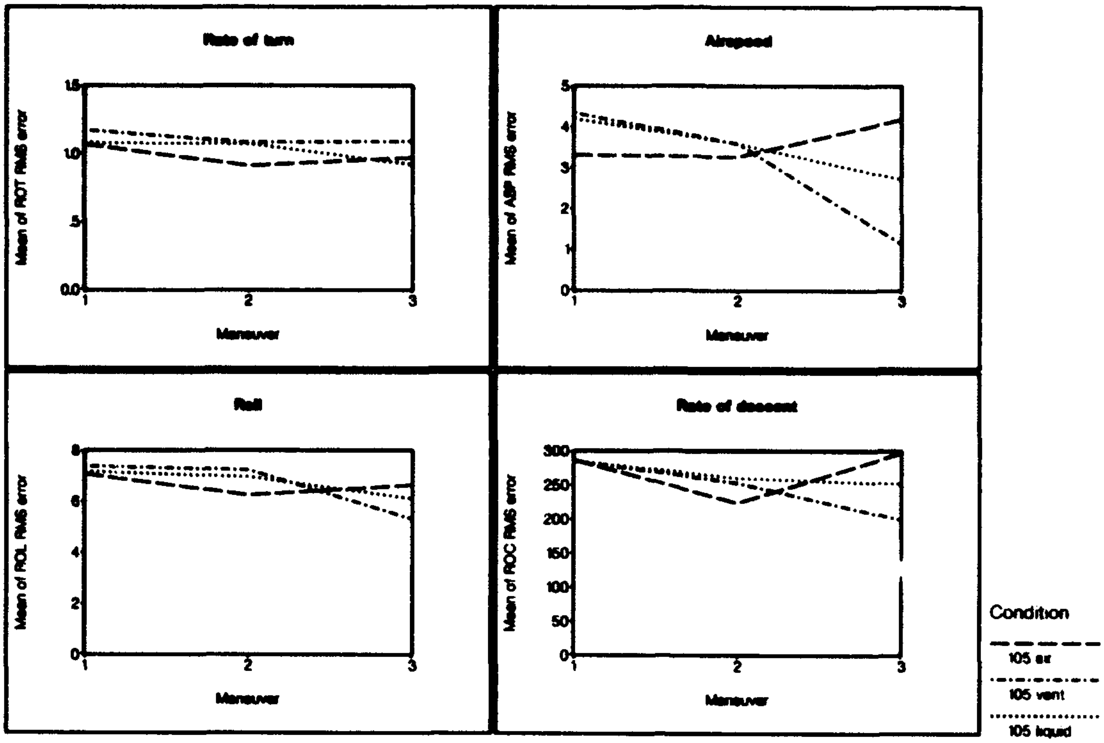

Figure 3. Left descending turn RMS error by maneuver, 105°F.

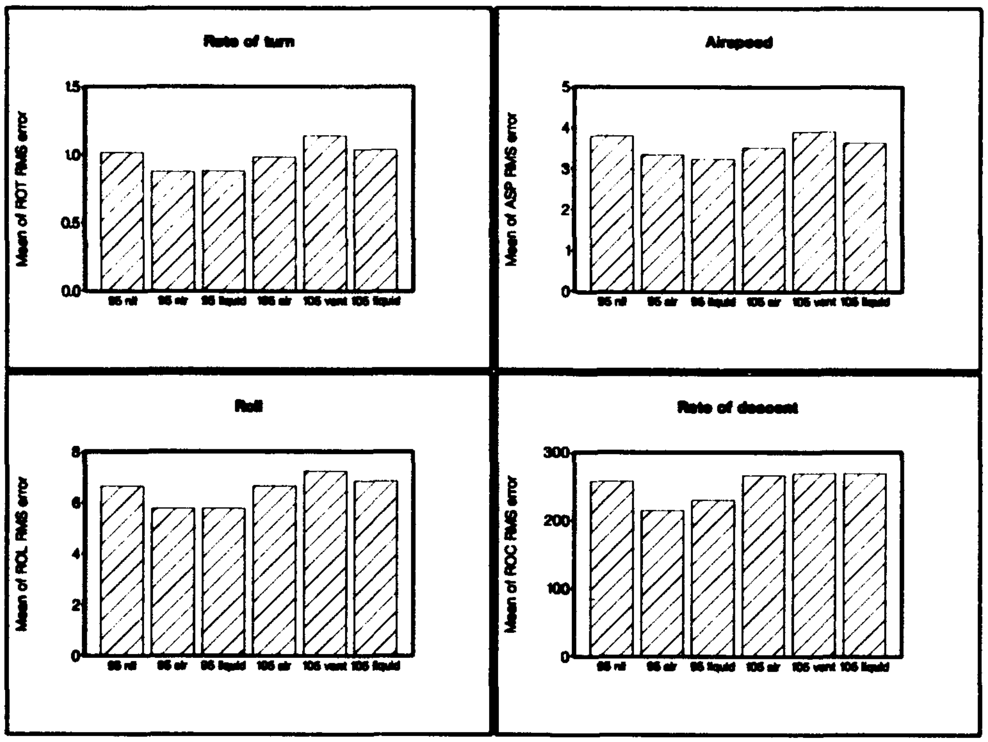

Figure 4. Left descending turn mean RMS error by condition.

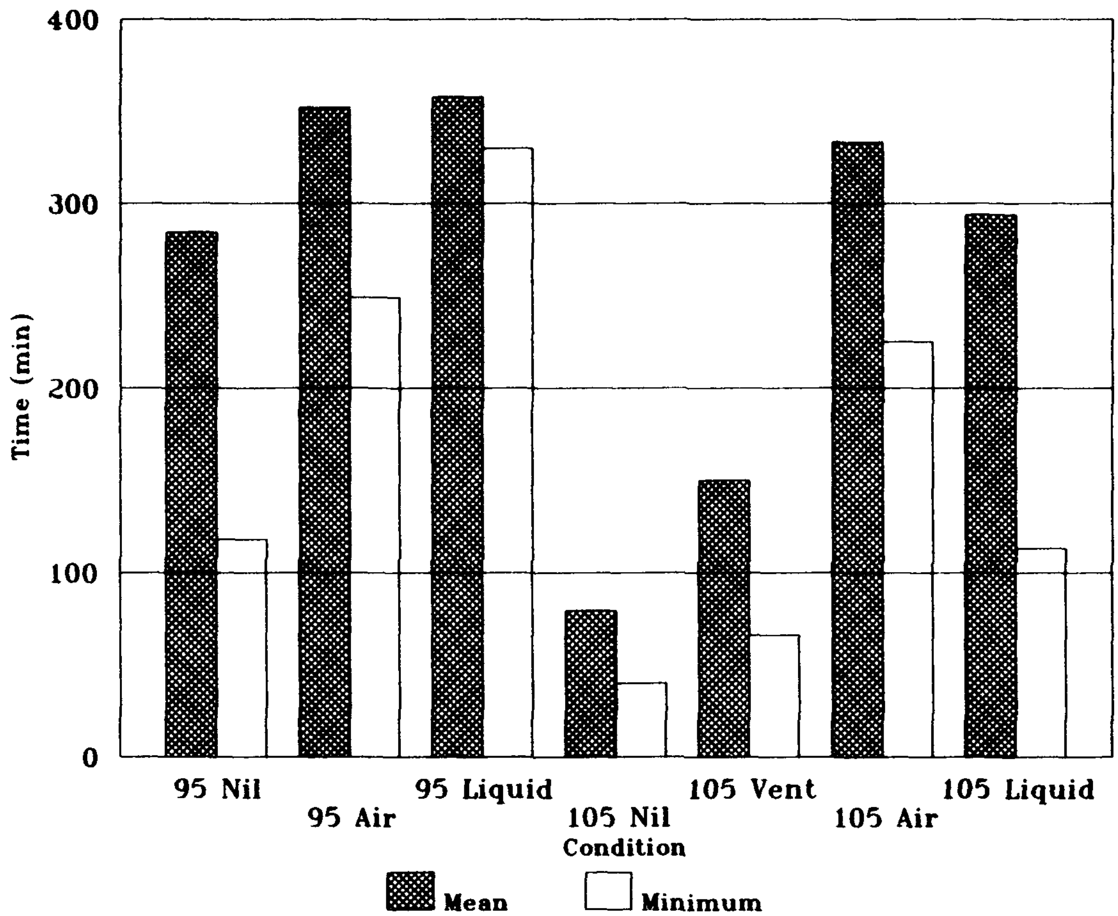

Figure 5. Mean survival time.

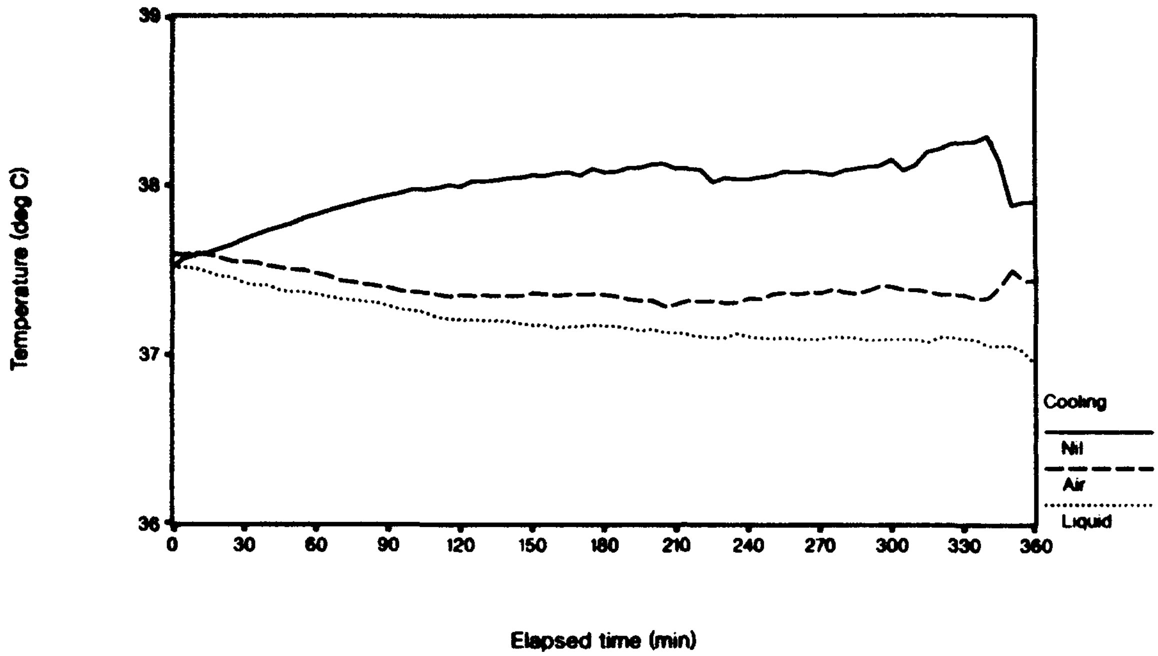

Figure 6. Mean rectal temperatures, 95°F.

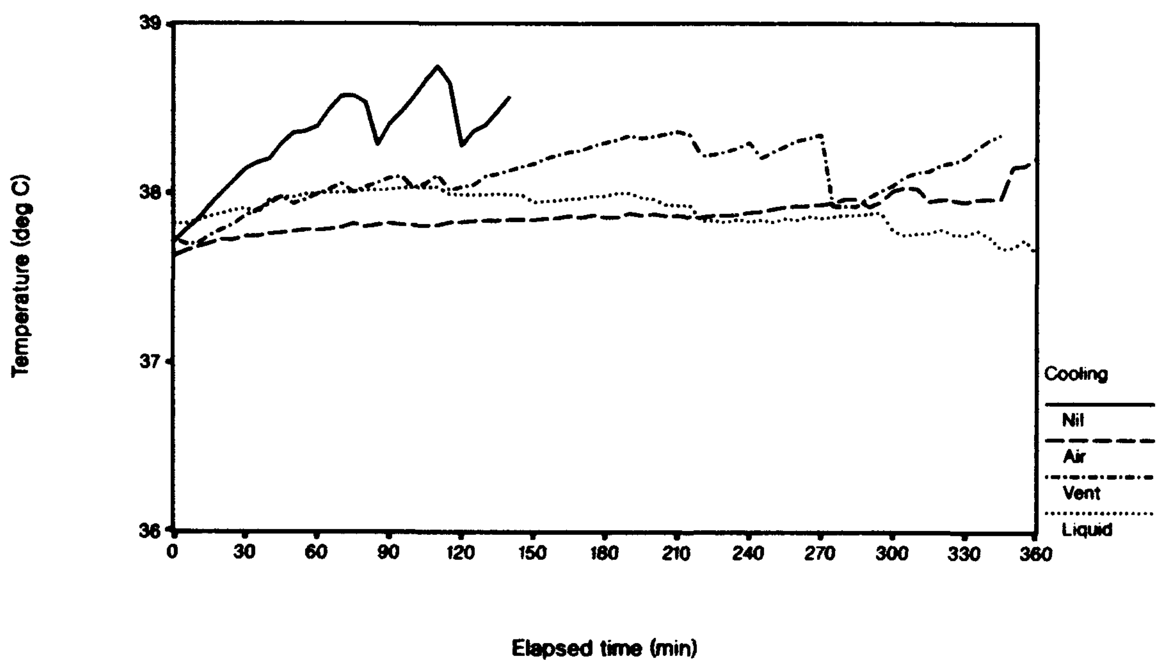

Figure 7. Mean rectal temperatures, 105°F.

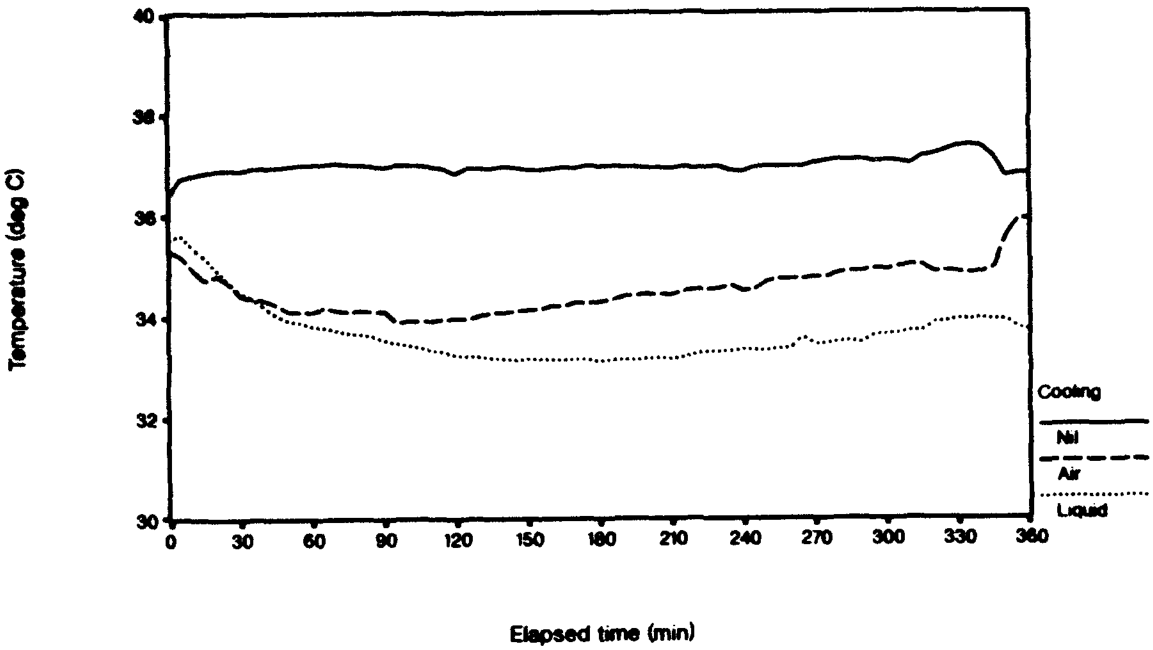

Figure 8. Mean skin temperatures, 95°F.

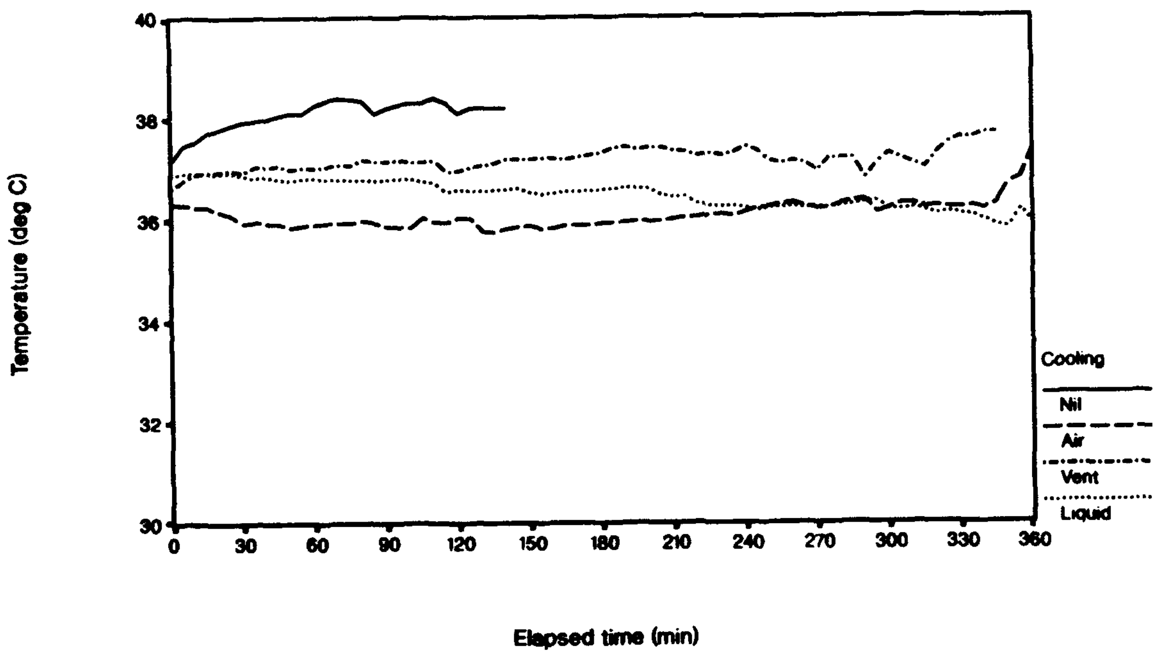

Figure 9. Mean skin temperatures, 105°F.

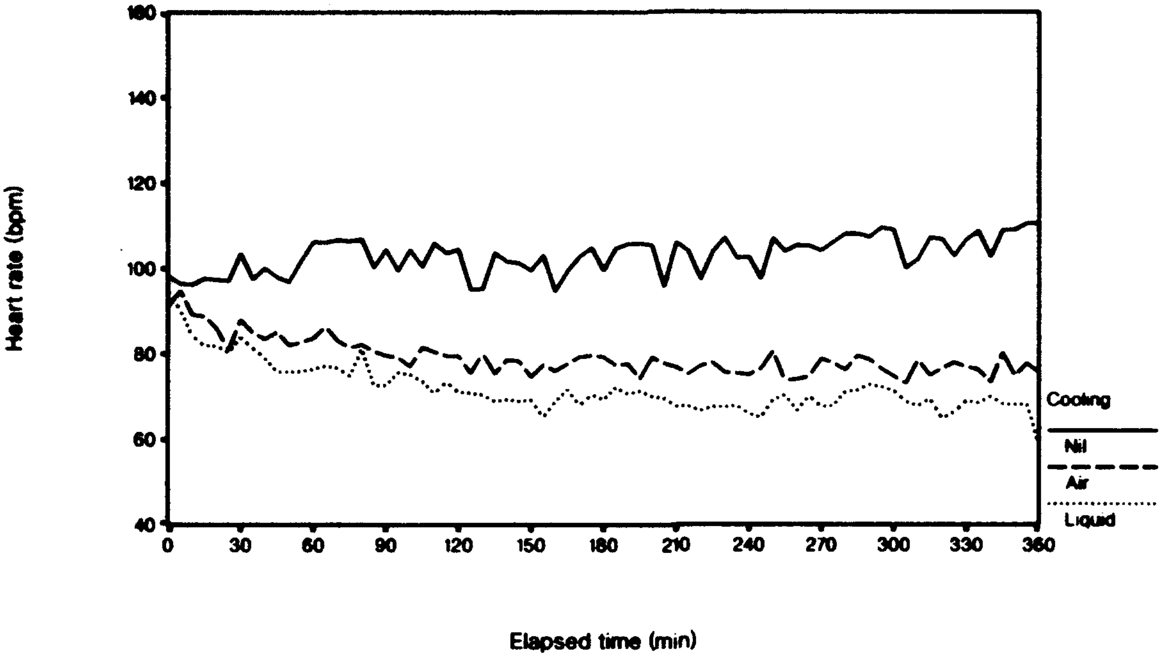

Figure 10. Mean heart rates, 95°F.

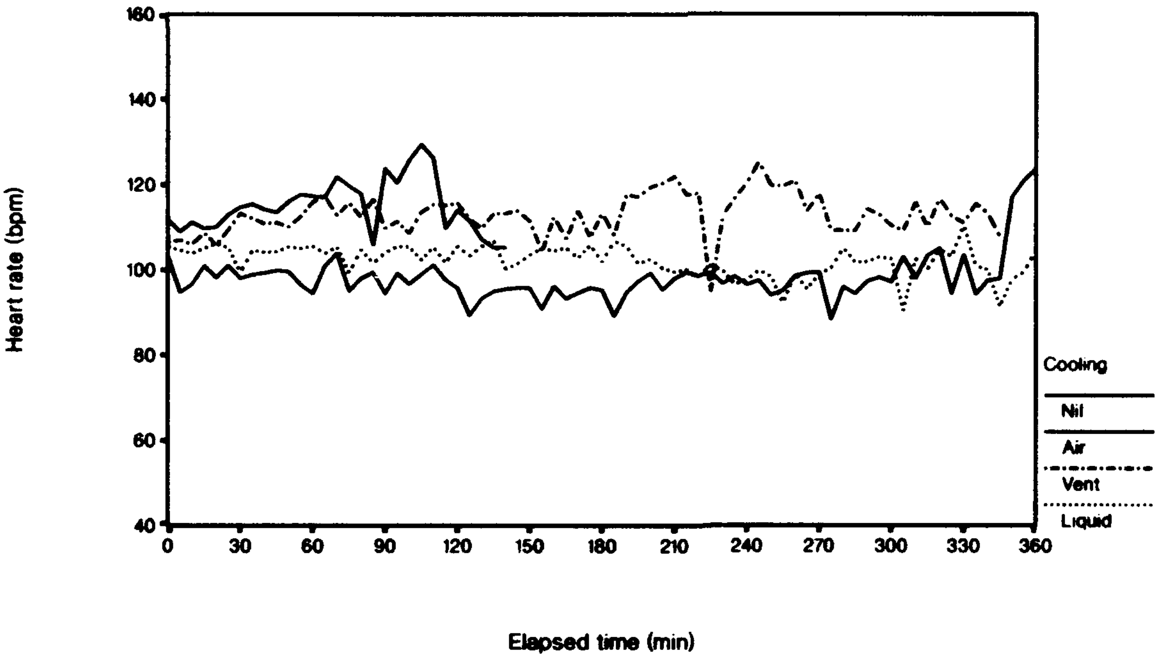

Figure 11. Mean heart rates, 105°F.

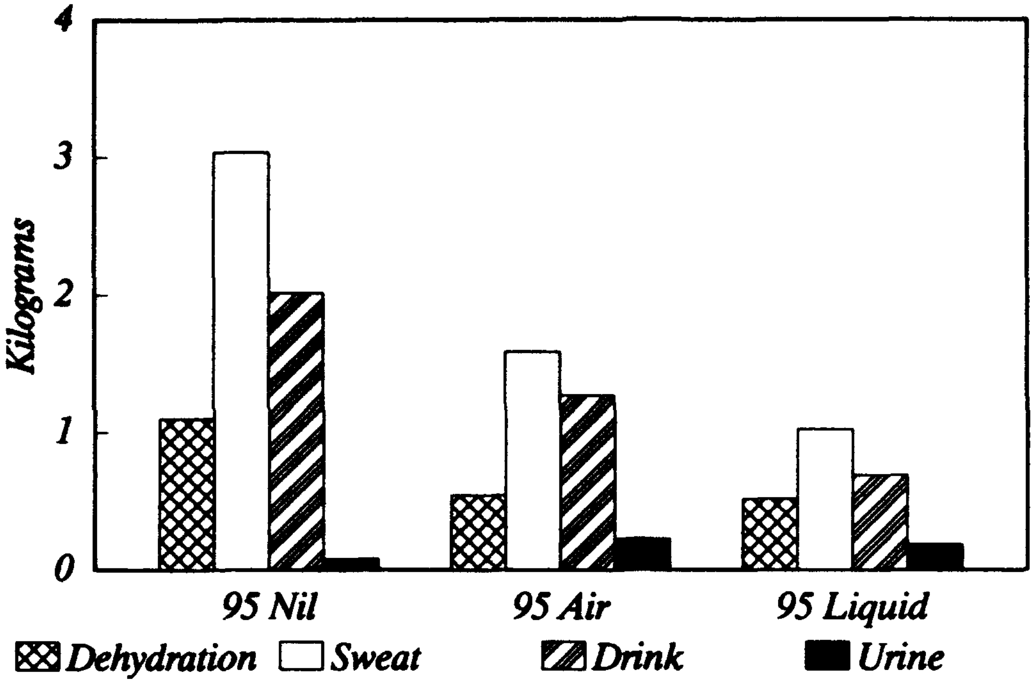

Figure 12. Water balance by weight, 95°F.

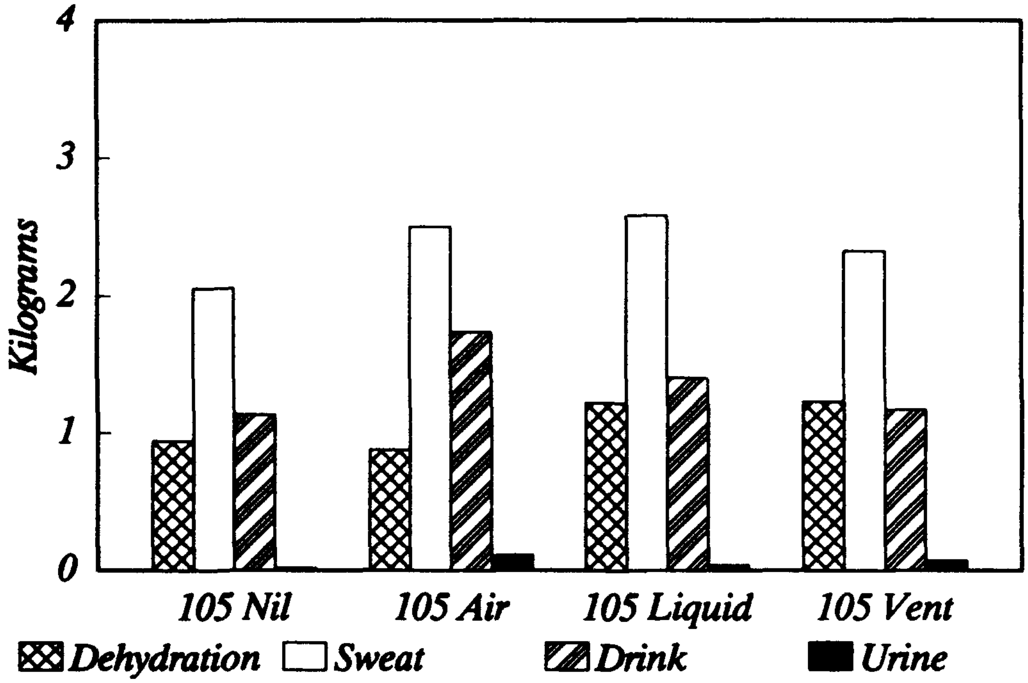

Figure 13. Water balance by weight, 105°F.

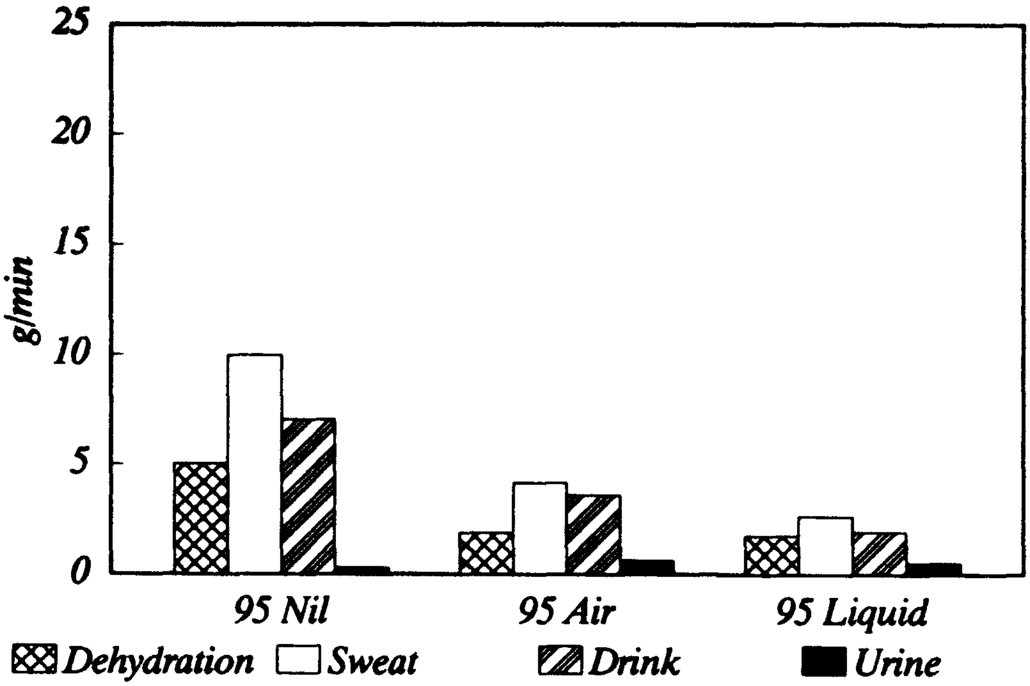

Figure 14. Water balance by rate, 95°F.

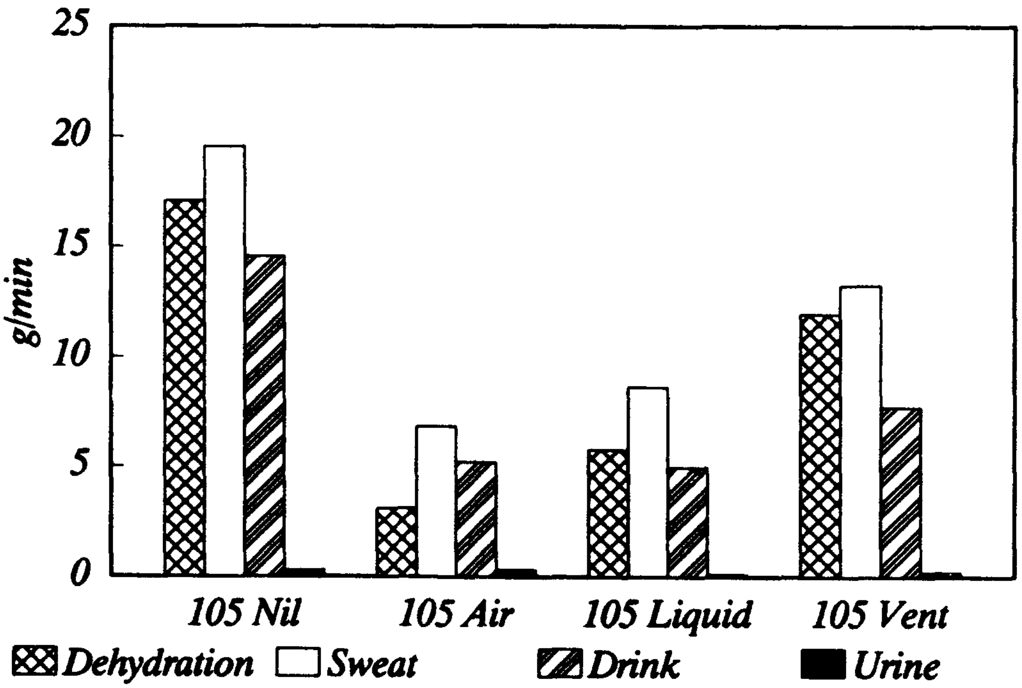

Figure 15. Water balance by rate, 105°F.

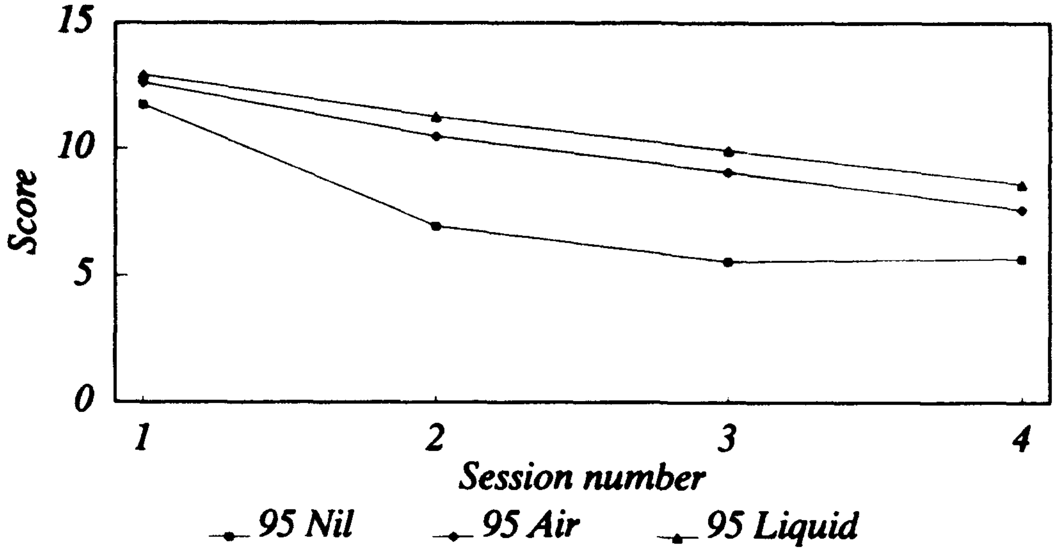

Figure 16. Fatigue checklist score, 95°F.

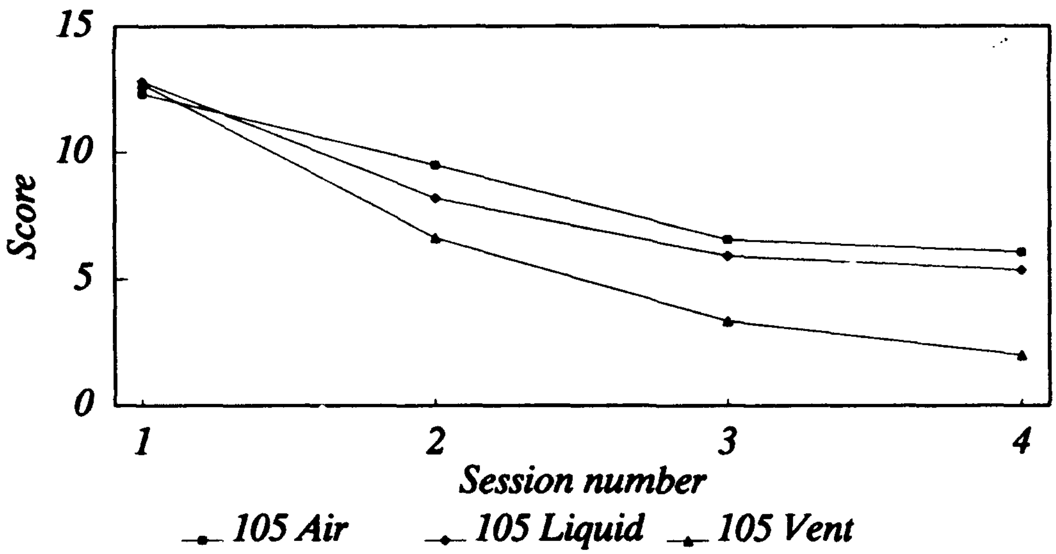

Figure 17. Fatigue checklist score, 105°F.

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Gulf conflict	Resuscitation	Life support equipment

14. Abstract

Extreme temperatures, both hot and cold, can severely restrict the ability of aircrew and support personnel to accomplish their missions. Under emergency conditions of bail-out, ejection and ditching of fixed or rotary-wing aircraft on land or in water, the survival rate of aircrew and passengers is also affected by the intensity of thermal stress experienced and the duration of exposure to the thermal stress. This has all recently been borne out by the experience of intense air operations in the Gulf War.

This Symposium reviewed the operational conditions experienced under extreme hot and cold weather.

The papers presented at this Symposium highlighted recent advances in thermal physiology, clothing sciences, personal flying equipment, and microclimate cooling. Emphasis was placed on the potential applications of these advances in situations where thermal stress, or the expectation of thermal stress, may confound the efficient achievement of mission objectives.

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